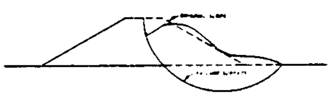
US Army Corps of Engineers



COMPUTER APPLICATIONS IN GEOTECHNICAL ENGINEERING (CAGE) and GEOTECHNICAL ASPECTS OF THE COMPUTER-AIDED STRUCTURAL ENGINEERING (G-CASE) PROJECTS

INSTRUCTION REPORT GL-87-1

USER'S GUIDE: UTEXAS3 SLOPE-STABILITY PACKAGE

VOLUME IV: USER'S MANUAL

by

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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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Relevant documentation

	UTEXAS2	UTEXAS3
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Theory	Volume II	Volume II and Appendix A of Volume IV
Example Problems	Volume I and some of Volume III	Volume IV and Volume III
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This report is the user's guide volume of the UTEXAS3 (University of Texas Analysis of Slopes - version 3) slope-stability package. This package describes a slope-stability program which can calculate the factor of safety by Spencer's method, Simplified Bishop's procedure, force equilibrium procedure with Corps of Engineers Modified Swedish side-force assumption of parallel side forces at a user-specified inclination and force equilibrium procedure with Lowe and Karafiath's side force assumptions. The program will calculate the safety factor for either a prescribed shear surface or for a search of the critical shear surface. Both circular and noncircular shear surfaces can be evaluated. There are seven options for the type of shear strength data and six options for specifying pore pressures. All analysis procedures and major features can be run in a single data file which is free-field format and utilizes command words. Graphics capability for displaying the input data and the final shear surface is available. Special capabilities include two-stage and three-stage stability

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computations to simulate undrained loading following a period of soil consolidation, external concentrated forces, internal slope reinforcement, curved (multilinear) shear strength envelope, anisotrophic shear strength, and the ability to have multiple piezometric lines. Six conceptual examples are included to illustrate data input procedures and computations analyses.

PREFACE

This report describes the capabilities of the two-dimensional slope-stability analysis package UTEXAS3 and provides instructions for running the code. UTEXAS3 represents several enhancements to the original program, UTEXAS2. Guidance relative to UTEXAS2 was originally contained in three volumes (User's Guidelines, Theory, and Example Problems). Although the program has been renamed (UTEXAS3) and contains significant enhancements, this report is treated as Volume IV of the series. Volume IV contains complete user guidelines for UTEXAS3. Included herein are instructions for data input and graphics, details about the output, search procedures, theory on the multi-stage analysis, and error message explanations. The four examples contained in Volume I plus two additional examples illustrating the major enhancements are included to illustrate the material in the text. This work is a product of the US Army Corps of Engineers Slope-Stability Task Group. The group is a combined effort of the Computer Applications in Geotechnical Engineering (CAGE) and the Geotechnical Aspects of the Computer-Aided Structural Engineering (G-CASE) projects. Both projects are sponsored by Headquarters, US Army Corps of Engineers (USACE). The USACE Technical Monitor is Mr. Art Walz, Directory of Civil Works, Engineering Division, Geotechnical and Materials Branch.

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This report was assembled by Mr. Earl V. Edris,Jr., Soil Mechancis Branch (SMB), Soil and Rock Mechanics Division (SRMD), Geotechnical Laboratory (GL), WES. Dr. Stephen G. Wright, Ashley H. Priddy, Centennial Professor in Engineering, Department of Civil Engineering, University of Texas at Austin, wrote the program user's manual, the contents of which make up Parts II and III and Appendixes A, C, and portions of B of this report under contract number DACW39-89-C-0024. Mr. Mike Pace, Scientific and Engineering

Applications Center, Information Technology Laboratory (ITL), WES, incorporated the graphics described in Part IV.

The CAGE project was managed and coordinated by Mr. Edris, and was under the supervision of Mr. W. Milton Myers, Chief, SMB, and Dr. Don C. Banks, Chief, SRMD, GL, and under the general supervision of Dr. William F. Marcuson III, Director, GL. The G-CASE project was managed and coordinated by Mr. Reed Mosher, Interdisciplinary Research, ITL, and under the general supervision of Dr. N. Radhakrishnan, Chief, ITL, WES. The material for this report was edited by Mrs. Joyce H. Walker, ITL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

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* Appendix E is included in diskette form.

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
foot-pounds (force)	1.355818	metre-newtons or joules
pounds (force)	4.448222	newtons
pounds (force) per square foot	47.88026	pascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

USER'S GUIDE: UTEXAS3 SLOPE-STABILITY PACKAGE

PART I: INTRODUCTION

1. UTEXAS3 (University of TEXas Analysis of Slopes - Version 3) is a general-purpose two-dimensional computer program for slope-stability computations. The original version of UTEXAS2 was released to the Corps of Engineers in August 1987. Since the initial version, some additional changes have been made to the program. The most significant changes to UTEXAS2 have been the addition of an option allowing the user to specify internal soil reinforcement and the ability to graphically view most line and point information. The user's guide for the slope stability program UTEXAS2 was organized into three volumes. Volume I contains the user guidelines including instructions for data input, output interpretation, graphics, error message explanations, and four illustrative examples. Volume II contains the theory and derivations of the equations used in the UTEXAS2 program.

2. A new version of the slope stability program has been developed. This version named UTEXAS3 has the capability to perform two-stage and three-stage stability computations to simulate undrained loading following a period of consolidation of the soil. Such multi-stage stability computations are appropriate for modelling sudden drawdown and "pseudostatic" seismic stability analyses. Additional enhancements in the new version of the program include the ability to specify concentrated point forces either externally or internally in the slope and the ability to specify that internal reinforcement can distribute forces along the length of the reinforcement. Volume IV contains complete user guidelines for UTEXAS3 plus the theory and derivations of the multi-stage analysis. This includes everything contained in Volume I plus two additional examples illustrating the major enhancements in the program capabilities. Volume III consists of more comprehensive examples showing the capabilities and versatility of the UTEXAS3 program and illustrates most options offered by the program.

3. The example problems in Volume IV are intended for the beginning user who is not familiar with the program UTEXAS3. These examples illustrate data input procedures and computation analyses for a single circular analysis, a

single noncircular analysis (wedge), search routines for both types of shear surfaces, the new multi-stage analysis, and reinforcement capabilities.

4. Volume IV is organized into five parts. Part I is this introduction. Part II contains all the detailed data input information including a description of the specific groups of input data, the general requirements of data for the program, the terminology and nomenclature used, and an introduction to the input data. The printed output produced by the program is described in Part III. Part IV includes pre-processor and post-processor details. For the initial release of this program, the graphics described in Part IV are limited to input graphics. Interactive data entry programs and output graphics are scheduled to be available in the Winter 92 timeframe. The user's guide will be updated when each of these features is released. The six example problems are contained in Part V with sample input and output files contained on a computer disk as Appendix E.

5. UTEXAS3 has the capability to perform two-stage and three-stage stability computations to simulate undrained loading following a period of consolidation of the soil. Such multi-stage (two-stage and three-stage) stability computations are appropriate for sudden drawdown and seismic "pseudostatic" stability analyses using consolidated-undrained strength test data. Two-stage and three-stage stability computations are described in Appendix A.

6. As with UTEXAS2, UTEXAS3 has outstanding diagnostic information. The input data ERROR messages make it easy to identify input errors. WARNING messages indicate that error conditions exist and should be evaluated. CAUTION messages indicate that there could be an error but the solution could be correct. All ERROR, WARNING, and CAUTION messages are explained in Appendix B of this report. The WARNING and CAUTION messages require the engineer to evaluate the output data to determine if the results are valid and reasonable. The most commonly occurring WARNING and CAUTION messages include negative side or shear forces, negative normal stresses, and side forces out of acceptable bounds. These generally indicate either a tension crack is needed for realism or a noncircular shear surface should be used. Any of the messages that occurred during the example runs are included and discussed in detail in the various examples.

7. Appendix A contains the current array size restrictions. A short form for checking data files is contained in Appendix D.

PART II: DATA INPUT
(Wright, 1991)

Introduction

8. The program UTEXAS3 computes a factor of safety F defined as

$$F = \frac{s}{\tau} \tag{1}$$

where, s is the available shear strength of the soil and τ is the shear strength (shear stress) required for just-stable equilibrium. The definition of the factor of safety given by Equation 1 is the one most commonly employed for slope stability analyses. The factor of safety is computed for an assumed shear (potential sliding) surface employing a method of slices. The program permits the user to select one of several procedures for computing the factor of safety. The procedures which may be selected are:

a. Spencer's procedure (Spencer, 1967; Wright, 1969).

b. Bishop's Simplified procedure (Bishop, 1955).

c. The US Army Corps of Engineers' Modified Swedish procedure (Headquarters, Department of the Army, 1970).

d. Lowe and Karafiath's (1960) procedure.

Further details regarding the implementation of these procedures are given in paragraphs 79 through 132 where the specific input data used to select the procedures are described. The theoretical derivations of the equations used to compute the factors of safety by these procedures are presented in Volume II and by Wright (1991). Although UTEXAS3 contains several procedures for computing the limit equilibrium factor of safety, Spencer's procedure is recommended and is automatically selected by the program unless input data designate otherwise. Spencer's procedure is the only procedure which addresses complete static equilibrium for each slice and, accordingly, it is the more statically correct procedure available in the computer program.

9. The factor of safety may be computed using either circular or general shaped, noncircular shear surfaces. Either the shear surfaces may be specified as individual surfaces, one-by-one by the user, or the program can be directed to automatically search for a most critical shear surface having a

minimum factor of safety. Regardless of the option chosen, the user will generally be most interested in the critical shear surface with the lowest factor of safety.

10. The slope geometry and soil profile are described by a series of straight, "profile" lines whose end-point coordinates are input to the computer program. The material beneath a given profile line is assumed to have a given set of properties (shear strength, unit weight, etc.) until the next, lower profile line is encountered. A number of different characterizations of shear strengths and pore water pressures (groundwater) can be selected by the user to describe a particular problem. In addition, the user may specify external loads on the surface of the slope to represent loads due to water, stockpiled materials, vehicles, etc. External loads may be either distributed loads (Surface Pressures) or point forces (Concentrated Forces). Point forces may also be specified internally in the slope. Finally, internal reinforcement with distributed forces along the length of the reinforcement may be specified.

General Description of Input Data Requirements

11. General formats and requirements of input data for UTEXAS3 are described in this section. The sequence of input data, the coordinate system and units used, and the formats used by the computer program to read data are described.

Sequence of Input

12. The input data are organized into a series of ten logical "Groups." The contents of individual Groups are discussed later group-by-group in paragraphs 27 through 132. The order in which one Group of data is input relative to another Group is selected by the user and any order may be used. The specific order selected is indicated to the computer program through the use of "Command Words" which are described in paragraphs 22 through 26. Three groups of data (Profile Lines, Material properties, and Analysis/Computation) are mandatory for the program to execute. Other groups of data are optional and may be omitted by the user depending on the particular problem being solved.

13. Two-stage and three-stage computations require that two separate sets of data be entered for the following Groups:

a. Group C - Material properties.

b. Group D - Piezometric lines.

c. Group E - Values for pore pressure interpolation.

d. Group G - Surface pressures.

e. Group H - Concentrated forces.

One set of data in each Group is for the first stage computations (before sudden drawdown or earthquake loading); the second set of data is for the second and third stage computations (after sudden drawdown or during earthquake). Second and third stage computations share the same set of data (See Appendix A). Data for the first and second stage are entered in the same format.

14. The stage for which data are being entered is designated using a global Command Word (See Command Words "FIR" and "SEC" described in paragraphs 22 through 26). A given stage remains the active stage for data being entered until the input stage is altered by an appropriate Command Word ("FIR" or "SEC").

Only one set of data is required for the following groups:

a. Group A - Heading (actually any number of sets of headings may be interspersed with data for various stages and among various groups).

b. Group B - Profile lines.

c. Group F - Slope geometry.

d. Group J - Reinforcement (reinforcement is applied for both stages of computations).

e. Group K - Analysis/Computation.

Data used for the first stage of two-stage or three-stage computations are treated internally in the computer program identically to data which are entered for conventional, single-stage slope-stability computations. The program assumes that data are for the first, or conventional, stage of computations. Accordingly, if a stage is not declared using a Command Word, the data are automatically treated as conventional, first-stage data.

Coordinate System

15. All coordinates are defined using a right-hand coordinate system with the x axis being horizontal and positive to the right, and the y axis being vertical and positive in the upward direction. The origin of the coordinate system may be located arbitrarily; however, the origin should be in the vicinity of the slope, within a maximum distance of ten times the slope height. This is recommended because moments are taken about the origin of the coordinate system, and numerical round-off errors could result if the moment arms for forces become excessively large. No restriction is placed on the sign of the coordinate values, and both positive and negative values may be used in the same problem.

Units for Data

16. The input data should be in consistent units of length and force. Output formats are set assuming that units will be in feet (for length) and pounds (for force). Units other than feet and pounds may be used; however, the computer output may either overflow some output fields or have too few significant figures to be meaningful.

General Recommendations and Cautions Regarding Free Water and Submerged Slopes

17. In several cases it is possible to "model" conditions for submerged slopes in more than one way; however, in these cases one way is usually considered preferable to others. In the case of slopes where free water exists above the ground surface, the presence of free water might be modeled in either of two ways: (1) The water may be represented by a series of equivalent "Surface Pressures" (see paragraphs 62 through 67 - Group G Data for Surface Pressures), or (2) the water may be represented as any other material (e.g. soil) using appropriate "Profile Lines" (see paragraphs 28 through 34 - Group B Data for Profile Lines) and assigning zero strength and a unit weight equal to the unit weight of water for the material properties (see paragraphs 35 through 44 - Group C Data for Material Properties). A very limited number of computations have been performed in which free water has been represented in both ways and the resulting factors of safety were essentially identical. However, this may not always be the case. IT IS STRONGLY RECOMMENDED THAT FREE WATER BE REPRESENTED BY "SURFACE PRESSURES" IN ALL CASES, i.e. by (1) above. There is at least one case where the second alternative of representing the water as a material may lead to unintended results. That is in the case where a seismic coefficient is being used. In the case of a seismic coefficient, the seismic coefficient will be applied to all materials and if the water is represented as a material, in the manner of (2) above, the water as well as the soil will receive seismic forces, which may lead to unintended results.

18. In the case of submerged or partially submerged slopes, submerged (buoyant) unit weights may sometimes be used to account for the effects of submergence. The use of submerged unit weights is discussed in further detail in paragraphs 35 through 44. However, in general USE OF SUBMERGED UNIT WEIGHTS IS NOT RECOMMENDED.

Dimensioned Array Sizes

19. A number of quantities which are either input as data or calculated by the computer program are stored in dimensioned arrays. The computer program will check these quantities and issue an error message when a dimensioned array size is exceeded. Presently the arrays are dimensioned to what have

been found to be convenient sizes for typical problems. It is anticipated that array sizes will probably be changed from time-to-time. Array sizes in effect at the time this documentation was prepared are given in Appendix C; however, the specific version of the computer program to which the user has access may have had the array sizes changed.

Formats for Reading Input Data

20. All numerical data are input and read in a "free-field" format. When more than one numerical value, or alphanumeric character string, is to be input on a given line of data, the values (or character strings) are separated by one or more blanks. Commas are not allowed as separators. The first numerical value or alphanumeric character string on a line of data does not need to be left-justified; the program will scan the line of input until the first non-blank character is located and, thus, any amount of indentation is permissible. In most cases the program will check for the required number of numerical values on a line of input and will issue an error message if an insufficient number of quantities is input.

21. A number of the sets of input data described later involve several lines of similar data, which must be terminated by a blank line. A blank line is not the same as a line containing zeros; a blank line must contain no alphanumeric or special characters.

Command Words

22. "Command Words" are used in the input data to designate that a particular Group of data (e.g., material properties, slope geometry, etc.) is to immediately follow. For example, the data defining the coordinates of lines used to describe the soil profile geometry are preceded by a line of input data with the Command Word(s) "PROFILE LINES." The computer program reads this line of data and determines that data for the "Profile Lines" are to be read next. The user should follow the Command word "PROFILE LINES" with the Group B, Profile Line data, as described in paragraphs 28 through 34.

23. Command Words are also used to direct the program to take action which may require no following data. For example, the special Command Word "COMPUTE" directs the program to temporarily stop reading data, check the data which have been read for correctness and completeness, and then perform computations for the factor of safety and associated slice forces. Once computations are complete, the program will then return to reading additional input data if desired. (The program attempts to read data until the end-of-file is detected.) Any additional data which are input after the Command Word "COMPUTE" may be either for an entirely new problem or may simply change one item of data before the Command Word "COMPUTE" is reissued to execute a new series of computations. In general, all previous data are retained either until new data are input by the user to change the old data or a special Command "Word" consisting of at least three asterisks (*) is issued.

24. Several Groups of data (Groups B, D, E, F and G) may be input in two modes, "Normal Mode" and "Modify Mode," which are selected through use of Command Words. Normal Mode is considered to be the normal mode of input and is initially assumed to be the input mode by the program. Modify Mode allows data within certain Groups to be selectively changed without input of all data in the group. The user may randomly "switch" between Normal and Modify Modes of input. The beginning user should chose the Normal Mode which is the default input mode used by the program.

25. The allowable Command Words and their meaning are described in Tables 1 and 2. Table 1 contains the Command Words which must be immediately followed by additional data. Table 2 contains the Command Words which require

no further data. The Command Words are generally shown as being one or more words of variable character length; however, <u>only the first three characters are actually read</u> and used by the program. (Leading blanks on a line are ignored, but all blanks following the first non-blank character are considered.) The key first-three characters of the Command Words are capitalized and underlined in Tables 1 and 2 to highlight their significance. The beginning user is encouraged to study each of the Command Words in Tables 1 and 2; the Command Words reflect many of the features and options of the computer program.

26. UTEXAS3 has capabilities for creating and reading information from separate external files to support future graphics programs as well as to provide the capability for reading data created by preprocessor programs which may be developed in the future.

Table 1

Command Words which Designate and Require Additional Data to Immediately Follow

Command Word	Description and Meaning
HEAding	Designates that data which are to immediately follow contain a heading to be printed as an output heading. See Group A data description in paragraph 27.
PROfile line data	Designates that data which are to immediately follow are for the profile lines. See Group B data description in paragraphs 28 through 34.
MATerial property	Designates that data which are to immediately follow are for material (soil) properties. See Group C data description in paragraphs 35 through 44.
PIEzometric line data	Designates that data which are to immediately follow are for piezometric lines. See Group D data description in paragraphs 45 through 50.
INTerpolation data for pore water pressures	Designates that data which are to immediately follow are for points used to interpolate pore water pressures. See Group E data description in paragraphs 51 through 54.
SLOpe geometry data	Designates that data which are to immediately follow are for the slope geometry. See Group F data description in paragraphs 55 through 61.
SURface pressure data	Designates that data which are to immediately follow are for normal and shear stresses acting on the surface of the slope. See Group G data description in paragraphs 62 through 67.
FORces	Designates that data which are to immediately follow are for concentrated forces acting either on the surface of the slope or internally in the slope. See Group H data description in paragraphs 68 through 72.

(Continued)

Table 1 (Concluded)

Command Word	Description and Meaning
REInforcement data	Designates that data which are to immediately follow are for internal reinforcement in the soil. See Group J data description in paragraphs 73 through 78.
ANAlysis and computation data	Designates that data which are to immediately follow are needed for the stability computations. See Group K data description in paragraphs 79 through 132.

Table 2

Command Words Which Do Not Necessarily Require Additional Data to Follow

Command Word	Description and Meaning
*********	Three or more asterisks (*) may be optionally used to separate distinctly different sets of data and problems. Then, if an error is encountered in any data for one problem, the program will skip the remaining data up to this line of asterisks and begin with the new set of data; all data specified previous to the line of asterisks are ignored for the next problem. (This is true regardless of whether or not errors are encountered.)
ASCii output file format activated	Designates that the external data file to be written and read is to be an ASCII file. See Command Words "WRIte" and "REAd". Applicable only when used with graphics and preprocessor programs.
BINary output file format activated	Designates that the external data file to be written and read is an unformatted ("binary") file. See Command Words "WRIte" and "REAd". Applicable only when used with graphics and preprocessor programs.
COMpute results	Designates that computations are to be performed. When this Command Word is read, the program checks all of the data currently read and proceeds with computations. Once computations have been completed, the program returns to reading Command Words and new data. Unless specifically directed (i.e., by three asterisks, "***") all old data are retained and new data read simply replace selected old data. Thus, all or only a small part of data may be changed for the next problem.
FIRst stage computation data	Designates that data in the Groups which follow will be for conventional (single-stage) computations or the first stage of two-stage computations. If the data which follow are of a type that does not depend on the stage, e.g. profile lines, this Command Word has no effect. Note: Any Command Word beginning with the numeral "1" will also be interpreted as the Command Word "FIRst".

(Continued)

Table 2 (Continued)

Command Word	Description and Meaning
MODify mode	Designates that the program is to be placed in Modify Mode for input of data: Certain groups of data (Groups B, D, E, F, G and H) can be input in either a Normal Mode or a Modify Mode. In the Modify Mode more selective changes to a portion of the data can be made, as described in later paragraphs for each of the Groups where this option is available.
NO compute	Designates that no computations are to be performed, but directs the program to perform the checks of input data and then resume reading input data. This is convenient for debugging data and the "NO COMPUTE" can later be re-edited to "COMPUTE" to activate execution.
NORmal mode	Designates that the program is to be returned to the Normal Mode after being in the Modify Mode described above. These modes may be changed at any time and in any pattern. The "normal" mode is set initially and after "***" are encountered.
OFF plot output	Deactivates the plot (graphics) output so that the plot file(s) will no longer be written when the Command Words "COMpute" or "NO compute" are encountered subsequently. Applicable only when used with graphics and preprocessor programs.
PLOt output activated	Activates the plot (graphics) output so that the plot file(s) will be written whenever the Command Words "COMpute" or "NO compute" are encountered subsequently. Applicable only when used with graphics and pre-processor programs.
PRInt input data	Designates that all subsequent input data are to be printed. This is the default set initially and after "***" are encountered.
REAd external file	Designates that the external file is to be read in as input data. The external file must have been previously created by UTEXAS3 (via the WRIte Command Word) or by another suitable program. Applicable only when used with graphics and preprocessor programs.

(Continued)

Table 2 (Concluded)

Command Word	Description and Meaning
SECond stage computation data	Designates that data in the Groups which follow will be for the second stage of two-stage computations. If the data are of a type that does not depend on the stage, e.g., profile lines, this Command Word has no effect. Note: Any Command Word beginning with the numeral "2" will also be interpreted as the Command Word "SECond".
SUPpress printing input data	Designates that all subsequent input data are not to be printed. Input data may be alternatively printed and suppressed among Groups for a single problem, i.e., "PRI" and "SUP" could appear several times in the data for a single problem if necessary.
WRIte external file	Designates that an external file is to be written to be read in as input data at a later time. Applicable only when used with graphics and preprocessor programs.

Group A - Data for Heading (Optional)

27. The Group A data consist of a 3-line heading which is printed as a heading above each table of output. The heading may be changed at any stage of the input data, i.e., it can be changed between each group of data (B, C, D etc.) or it can be left the same for all groups. To change the heading at any time input the Command Word "HEA" (or "HEADING"). A blank heading is assumed both initially and immediately after "***" is encountered in the Command Words. The heading may be input while the program is operating in either the Normal Mode or the Modify Mode of input. There is no difference in the form of input of heading data for the two modes. The form of input is shown in Table 3.

Table 3

Group A - Heading Data Input Format

Input Line No.	Data Field No.	Variable/Description
1	1	HEADING(1)First line of heading; up to 65 characters including blanks.
2	1	HEADING(2)Second line of heading; up to 65 characters including blanks.
3	1	HEADING(3)Third line of heading; up to 65 characters including blanks.
		Resume input with Command Words after three lines of heading have been input. Three lines must be input; however, one or more of the lines may be blank.

Group B - Data for Profile Lines

28. Group B data consist of the "Profile Lines" which are used to describe the geometry of the soil profile and slope cross-section. Individual profile lines are defined by the coordinates of a series of points along each line from left-to-right (in the increasing x direction). The points are assumed to be connected by straight lines to represent a continuous, piece-wise linear, line. Vertical line segements are not allowed.

29. Beneath a given profile line the soil or other material is considered to be of a given type until another profile line is encountered. Each profile line has a "Material Type" associated with it; the material type is specified as part of the input data for the profile line. The material type indicates which set of material properties, specified in the Group C data (see paragraphs 35 through 44), is to be used for the soil beneath the profile line.

30. Several profile lines may be assigned the same material type. Segments or portions of segments of two different profile lines cannot coincide. If two segments coincide, it is not possible for the program to logically determine which of the two segments (profile lines) is to be associated with the underlying material. An error message is printed when two profile line segments coincide.

31. UTEXAS3 permits the user to describe a soil profile with "Profile Lines" and, then, to consider several slope geometries "cut" from the soil profile. The slope geometry data are input as Group F data; several sets of Group F data may be input for a given set of profile lines. The option of considering several slopes in a given profile is useful for trial embankment and excavated slope design. In the case of embankments the profile lines should include sufficient soil to encompass any potential embankment cross-section; excess soil above the slope will be ignored. In the case of excavated slopes the profile lines should define the original soil profile before excavation.

32. If the slope geometry (Group F) data are omitted (they are optional), the program will automatically generate the slope geometry using the uppermost profile line segments to create the surface profile. However,

once profile lines have been input and slope geometry data have been defined, either by Group F data or by generating them from the profile line data, the slope geometry remains in effect until specific action is taken to change the slope geometry by entering new Group F data. Accordingly, if new profile lines are entered, the previous slope geometry data will be retained, rather than new slope geometry data being automatically computed from the new profile line data. If new slope geomentry data are required, they must either be input as Group F data or a "null" set of slope geometry data must be input as described in paragraphs 55 through 61. New slope geometry data will be generated if a null set of data is entered for the slope geometry.

33. Once a <u>set</u> of profile lines is defined, they ordinarily remain in effect until specifically replaced, one-by-one by new data. As an example, suppose that five profile lines are initially defined and at a later time new data are input for just one profile line. The new data may either <u>replace</u> one of the "old" profile lines, the other four profile lines being unchanged, or add to the old profile lines, creating a total of six profile lines. Whether the new data replace or add to the old data will depend on the number (NLINE) of the new profile line. If a line having the same number as the new line exists, it will be replaced by the new data. If no line with the number of the new line exists, the new line is added to the previous lines. The only time profile line data are started entirely anew is when asterisks (***) have been input as a Command Word (see Table 2).

34. Group B data must immediately follow the Command Word "PRO" (or "PROFILE LINES"). The data may be input in either the Normal Mode or the Modify Mode. Input for the Normal Mode is described in Table 4; input for the Modify Mode is described in Table 5.

Table 4

Group B - Profile Line Data Input Format - Normal Mode

Input Line No.	Data Field No.	Variable	Description
1	1	NLINE	Number of the profile line to be defined next, i.e., on Line(s) 2 below. Any sequence of numbering and input of profile lines may be used.
1	2	MTYPE	Number of the material type for the material below the profile line.
1	3	LABEL	Any alphanumeric character(s) or character string(s) to be printed as a label for the profile line. Can be as many characters and/or blanks as will fit on an 80 column line (including Fields 1 and 2) up to a maximum of 65 characters or blanks. Can also be entirely blank.
2	1	XPROFL	X coordinate of point on the profile line which is currently being defined.
2	2	YPROFL	Y coordinate of point on the profile line which is currently being defined.

Repeat Line(s) 2 for additional points on the profile line in a left-to-right sequence. More than one pair of coordinates (XPROFL, YPROFL) may be entered on a given line of input data if desired; however, each line must contain complete pairs (2 values) for each point. Input a blank line to terminate data for the current profile line.

Repeat Lines 1 and 2, as sets, for additional profile lines. Lines may be input in any order. (Line numbers, NLINE, maybe missing from a sequence; however, there appears to be little need for omitting numbers from a sequence.) Input two blank lines after the last line of non-blank profile line data to terminate all Group B data and return to input of Command Words. The first blank line terminates the last profile line data set and the second blank line terminates the Group B data.

Table 5
Group B - Profile Line Data Input Format - Modify Mode

Input Line No.	Data Field No.	Variable/Description	
1	1	NPROF	Number of the profile line for which coordinate is to be changed.
1	2	NPOINT	Number of the point on the designated profile line where the coordinate is to be changed.
1	3	XPROFL	X coordinate of point on the profile line which is currently being defined.
1	4	YPROFL	Y coordinate of point on the profile line which is currently being defined.

Repeat Line(s) 1 for additional points whose coordinates are to be changed in Modify Mode. More than one set of data (4 quantities) may be entered on a given line; however, each line must contain integer multiples of 4 quantities, comprising complete data sets. Input a single blank line to terminate all Group B data and return to input of Command Words.

Group C - Data for Material Properties

35. The Group C data consist of material properties, which include the unit weights, shear strengths, and description of how pore water pressures, if any, will be defined for each of the materials in the soil profile. Each profile line, as described previously in paragraphs 28 through 34, must have a set of material properties. Requirements for the material property data and the form of the input data are described in this section.

Effective stress versus total stress analyses

36. The computer program permits analyses to be performed using either total or effective stresses to define shear strengths. In the case of total stresses the shear strengths are expressed by the equation

$$s = c + (\sigma)\tan\phi \tag{2}$$

where σ is the total normal stress on the shear plane, and c and ϕ are shear strength parameters expressed in terms of total stresses. For the case of effective stresses the shear strengths are expressed by

$$s = \bar{c} + (\sigma - u)\tan\bar{\phi} \tag{3}$$

where u is the pore water pressure, $(\sigma - u)$ is the effective normal stress, and $\bar{c}$ and $\bar{\phi}$ are shear strength parameters expressed in terms of effective stresses. The measured pore water pressure consists of three components, that due to the hydrostatic head, that due to consolidation or swell, and that caused by the tendency to change volume due to shear. Details about these components and when they should be considered are included in the upcoming or revised Slope Stability Manual. In the input of data to the computer program the values for "cohesion" and "friction angle" must be the appropriate total stress (c,ϕ) or effective stress $(\bar{c},\bar{\phi})$ values. The only other distinction that is made between total and effective stresses is that in the case of effective stresses the appropriate pore water pressures (including zero as a special case) must be specified, while for total stresses pore water pressures must be specified as zero.

37. The distinction between total and effective stresses is made on a material-by-material basis. Thus, the shear strengths of some materials may

be defined using total stresses while the shear strengths for other materials may be defined using effective stresses.

Strengths for
Multi-Stage Computations

38. When UTEXAS3 is being used for two-stage or three-stage stability computations, two complete sets of properties (shear strengths, unit weights and pore water pressures) must be entered for each of the two stages for which computations will be performed (Appendix A). The two sets of material properties are described in further detail in this section. If conventional computations are being performed, only one set of properties is required and the material in this subsection may be disregarded. For two-stage computations, the first set of material properties is used for the first stage computations; the second set is used for the second stage computations. Material properties for the first stage of two-stage computations are identical to those for conventional, single-stage computations. Data for the second stage of computations for some materials may be almost the same as those for the first stage. For example, in freely draining materials the strengths are specified using effective stresses for both stages. The strength parameters and method for describing pore water pressures (e.g., a piezometric line) may be the same for both stages; only the unit weights may change. For other materials data for the second stage will be somewhat different from the data for the first stage. Frequently, for the second stage "two-stage" strengths will be defined. Two special shear strength options (Options 6 and 7) exist for defining shear strengths for the second stage of two-stage computations. One option employs linear shear strength envelopes; the other option employs nonlinear envelopes.

Unit Weights

39. The unit weight which is specified for each material should be the total unit weight (total weight divided by total volume). In two cases the submerged (buoyant) unit weight of soil may be used; however, it is not necessary to use submerged unit weights in these two cases. In general, the use of submerged unit weights is not recommended.

a. The first case where submerged unit weights may be used occurs for total stress analyses where ϕ is equal to zero. In this case a submerged unit weight may be used for the portion of any soil which is submerged beneath water provided that there is no flow or tendency for flow (i.e., the hydraulic gradient is zero). If the submerged unit weight is used in this case, any surface loads due to

the overlying water must <u>not</u> be specified as surface pressures (see paragraphs 62 through 67 for description of Surface Pressures); the effects of the surface loads are already accounted for when the submerged unit weight is used. If there is flow of water (variable total head) or ϕ is not equal to zero, submerged unit weights must not be used for total stress analyses.

b. The second case where submerged unit weights may be used occurs in the case of effective stress analyses. Submerged unit weights may be used for the portion of any soil which is submerged provided that there is no flow of water and no hydraulic gradient. If the submerged unit weight is used, pore water pressures due to hydrostatic head and any surface pressures due to the water must <u>not</u> be specified in the input data; the effects of hydrostatic pore water pressures and surface pressures are already accounted for when the submerged unit weights are used.

If submerged unit weights are used for one material, they <u>must</u> be used for all materials for which the use of submerged unit weights is allowable, i.e., they must be used for all portions of materials which are submerged.

<u>Shear Strength Options</u>

40. Seven options are available for defining the shear strengths for each material. The first five options (Options 1 through 5) are applicable to conventional analyses and either the first, second, or third stage of multistage stability computations. The last two options are specifically for defining "two-stage" strengths to be used in two-stage and three-stage slope stability computations. The seven options are as follows:

a. <u>Option 1</u>. The shear strength is isotropic (shear strength is independent of the orientation of the failure plane) and is defined in a conventional manner, expressed by a Mohr-Coulomb cohesion (c) and friction angle (ϕ). For total stress analyses the cohesion and friction angle should be the values of c and ϕ determined using total stresses to plot the failure envelope. In the case of total stresses the pore water pressures must be specified to be zero. For effective stress analyses the values of c and ϕ ($\bar{c}$ and $\bar{\phi}$) should be values determined using effective stresses to plot the failure envelope. In the case of effective stresses appropriate pore water pressures will need to be specified.

b. <u>Option 2</u>. The shear strength varies linearly with depth below the profile line(s) to which the data apply. The value of the shear strength at points along the profile line and the rate of increase in shear strength with depth below the profile line are input as data by the user. If the same material exists above the profile line, the shear strength is assumed to <u>decrease</u> with depth <u>above</u> the profile line at the same rate that it <u>increases</u> with depth <u>below</u> the profile line. A negative value for the rate of "increase" is interpreted as a decrease in shear strength with depth below the

profile line and an increase in shear strength above the profile line.

The friction angle is assumed to be zero for Option 2 and the appropriate shear strength, depending on depth, is assigned as a cohesion value. Accordingly, Option 2 will generally only apply to cases where undrained loading of saturated soils is involved and where the computations are being performed using total stresses.

c. Option 3. The shear strength varies linearly with depth below a selected reference datum. The elevation (y) of the reference datum, the value of the shear strength at the elevation of the reference datum, and the rate of increase in shear strength with depth below the datum are input as data by the user. Option 3 is very similar to Option 2. The only difference is that in the case of Option 3 the shear strength varies with depth below a horizontal datum while, for Option 2, the datum is the profile line, which may or may not be horizontal. All features of the input data for shear strength are otherwise identical for Options 2 and 3.

d. Option 4. The shear strength parameters c and ϕ, or $\bar{c}$ and $\bar{\phi}$, as described for Option 1, vary with the orientation of the failure plane. Values of c and ϕ are input for selected failure plane orientations and linear interpolation is used to obtain values at orientations between the specified values. UTEXAS3 will later assign appropriate values of c and ϕ to each slice based on the orientation of the base of the slice; the base of the slice is considered to represent the failure plane and the inclination of the base of the slice corresponds to the failure plane inclination. (See paragraphs 79 through 132 regarding slices).

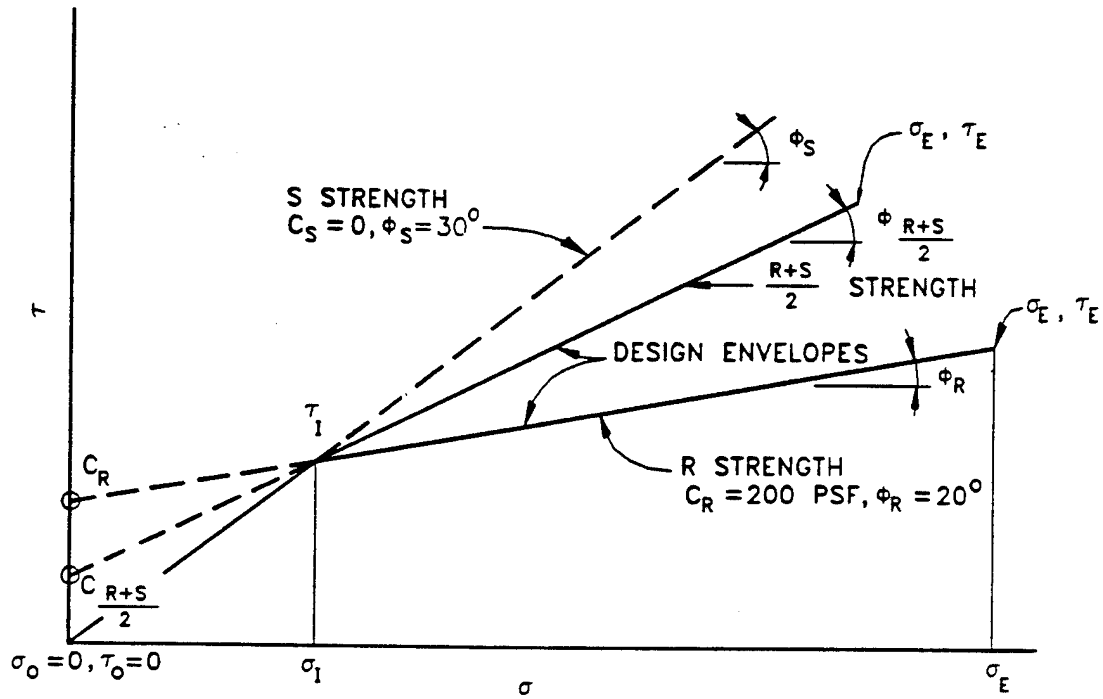
Failure plane orientations are specified in the input data by angles measured in degrees from the horizontal plane. Values may range from negative to positive with counterclockwise being positive and should encompass the maximum anticipated range of failure plane (shear surface) inclinations. The computer program will not extrapolate from the input data for angles outside the range encompassed by the input data. When the failure plane inclination falls outside the range of the data an error message will be issued by the program.

e. Option 5. The shear strength ("Mohr-Coulomb" type) envelope is nonlinear, i.e., it is not a single straight line and is used for single stage analyses. Values of shear strength (τ) are input for various values of total or effective normal stress (σ or $\bar{\sigma}$) to define points on a nonlinear shear strength envelope. The points are assumed to be connected by straight lines to form a piece-wise linear envelope. UTEXAS3 will later assign a shear strength to the base of each slice based on the total or effective normal stress on the base of the slice (see paragraphs 79 through 132 regarding slices). An iterative procedure is used to assign the shear strengths because the computed normal stresses depend on the shear strength. The computed normal stresses also depend on the factor of safety. Accordingly, shear strengths defined by a nonlinear shear strength envelope are assigned at the time the factor of safety is

computed. Because the solution for the factor of safety involves using a trial and error procedure, two levels of iteration are required when a nonlinear shear strength envelope is used: One level of iteration is for the factor of safety; the other level is for the shear strength. This option is used to represent bilinear strength envelopes that are required by EM 1110-2-1902 (Headquarters, 1970) for certain loading conditions. The R and S strength envelopes are combined to generate the bilinear envelope. The strengths are generally provided in terms of c and ϕ, and $\bar{c}$ and $\bar{\phi}$. However, values of shear strength and normal stresses are needed to define the envelope. Figure 1 shows both the graphical and computational methods that can be used to obtain the necessary values. The computer program will not extrapolate from the input data for values of the normal stress outside the range encompassed by the input data. When the normal stress falls outside the range of the data an error message will be issued by the program. In many cases this will require that points be defined along the shear strength envelope for negative as well as positive normal stresses, especially if the shear strength envelope has a "cohesion" intercept. Frequently the shear strength values (τ) for negative normal stresses will be defined to be zero, i.e. there will be no tensile strength.

f. Option 6. A "two-stage strength" is defined by two envelopes: (1) the conventional effective shear stress strength envelope derived from either consolidated drained (S) or consolidated-undrained ($\bar{R}$) triaxial tests with pore water pressure measurements, and (2) an envelope of τ_{ff} versus $\bar{\sigma}_{fc}$ derived from consolidated-undrained triaxial compression tests on specimens which have been consolidated isotropically. Each envelope is defined by its intercept value d_S ($=\bar{c}$) and d_R, respectively, and inclination angle ψ_S ($=\bar{\phi}$) and ψ_R, respectively (See Appendix A). Although the effective stress failure envelope for the two-stage strengths is usually identical to the effective stress envelope used for the first stage computations, the effective stress envelope must be specified again in the input data for the second stage computations.

g. Option 7. Two nonlinear (piece-wise linear) shear strength envelopes are defined for "two-stage" strength by Option 7. This option is identical to Option 6 except the design shear strength envelopes are nonlinear and two shear stresses are defined for each normal stress. The envelopes are defined for: (1) the effective stress envelope; and (2) the envelope of τ_{ff} versus $\bar{\sigma}_{fc}$ derived from R tests. The two nonlinear strength envelopes are defined in terms of points on the envelope, connected by straight lines. The envelopes are defined like the nonlinear envelope for strength Option 5. An effective normal stress and corresponding values of shear stress for the two envelopes are entered as data. Points on each envelope share common values of effective normal stress. Accordingly, whenever there is a break in either of the two envelopes a point must be defined on both envelopes.



EQUATIONS FOR σ_I, τ_I

$$\sigma_I \ \mathrm{TAN}\ \Phi_S = \sigma_I \ \mathrm{TAN}\ \Phi_R + C_R$$

OR

$$\sigma_I = \frac{C_R}{\mathrm{TAN}\ \Phi_S - \mathrm{TAN}\ \Phi_R}$$

$$\tau_I = \sigma_I \ \mathrm{TAN}\ \Phi_R + C_R$$

OR

$$\tau_I = \sigma_I \ \mathrm{TAN}\ \Phi_S$$

EQUATION FOR σ_E, τ_E FROM R ENVELOPE

$$\tau_E = \sigma_E \ \mathrm{TAN}\ \Phi_R + C_R \quad \mathrm{WHEN}\ \sigma_E > \sigma_I$$

EQUATION FOR σ_E, τ_E FROM (R+S)/2 ENVELOPE

$$\tau_E = \sigma_E \ \mathrm{TAN}\ \Phi_{\frac{R+S}{2}} + C_{\frac{R+S}{2}}$$

Figure 1. Graphical and computation methods used for obtaining necessary values for the bilinear strengths (A table of factors for converting Non-SI to SI (metric) units of measurements is presented on page 5.)

Pore Water Pressure Options

41. Six options are available for defining the applicable pore water pressure components for the individual materials as follows:

a. Option 1. No pore water pressures are to be used, i.e., total stresses are being used, or the pore water pressures are equal to zero.

b. Option 2. The pore water pressure is constant throughout the given material; the constant value of pore water pressure is then input. This option is seldom used.

c. Option 3. The pore water pressures throughout the material are expressed by a constant, given, value of the pore water pressure coefficient, r_u, (Bishop and Morgenstern, 1960). The pore water pressure coefficient is defined as

$$r_u = \frac{u}{\gamma h} \tag{4}$$

where u is the pore water pressure at any point and γh is the corresponding total vertical stress (overburden pressure). If this option is chosen, the value of r_u, is then input. In computing pore water pressures using a value of r_u the computer program calculates "γh" due to the weight of overlying soil, but excludes any added vertical stress due to Surface Pressures or Concentrated Forces which may be input as Group G and H data, respectively (see paragraphs 62 through 72).

d. Option 4. The pore water pressure is defined by a piezometric line; piezometric line data must be input separately by use of Group D data as described in paragraphs 45 through 50. The material property data must include an identification number for the piezometric line to be used. In computing pore water pressures from the piezometric line the computer program determines the vertical distance between the point of interest and the piezometric line and multiplies this distance by the unit weight of water to arrive at the pore water pressure. Pore water pressures are assumed to be positive below the piezometric line and negative above the piezometric line (see paragraphs 45 through 50 for more details).

e. Option 5. Pore water pressures are computed by interpolating pore water pressures from an irregular "grid" of pore pressure values, which are specified separately by Group E data, as described in paragraphs 51 through 54.

f. Option 6. Pore water pressures are computed by interpolating in a manner similar to that for Option 5, except that values of the pore water pressure coefficient, r_u, rather than actual values of pressure, are input and used for interpolation. The values of r_u are used and defined in the same manner as described for Option 3. Further description of the interpolation is presented in paragraphs 51 through 54. Option 6 is seldom used.

42. Normally, the UTEXAS3 will set any negative value of pore water pressure to zero before proceeding with further calculations; however, the user can optionally override this feature if desired (see Line No. 5, Field No. 3 in Table 6).

Form for Data Input

43. The form and guide for Group C data input are presented in Table 6. The Group C data must immediately follow the Command Word "MAT" (or "MATERIAL PROPERTIES"). Only the Normal Mode of input is available for material properties and will be used regardless of whether the Normal or Modify Mode is in effect.

44. Once data have been input for materials, the data remain in effect until specifically replaced, material by material, with new data. If new data are input for only one material, after data for several materials have been previously input, then the new data will either replace the data for one material or add to the existing data. If the material type (MTYPE - see Line No. 1, Field No. 1 of Table 6) for the new material is identical to one previously defined, the new data will replace the previous data for this material only. If the material type for the new material has not been previously defined, the new data are added to the old data which were previously defined. Thus, while a Modify Mode is not available for material property data, the Normal Mode permits data to be selectively changed. The only times material property data are started entirely anew is when asterisks (***) have been input as a Command Word (see Table 2).

Table 6

Group C - Material Property Data Input Format

Input Line No.	Data Field No.	Variable	Description
1	1	MTYPE	Number used to identify the material (=material type) for which data will follow on Line(s) 2 through 6. This number corresponds with the material type numbers input for profile lines in Group B data. The maximum number of materials allowed is equal to MAXMAT. (See Appendix A).
1	2	LABEL	Any alphanumeric character(s) or character string(s) to be printed as a label with data for the current material type. Can be as many characters and/or blanks as will fit on an 80-column line (including Field 1) up to a maximum 65 characters. Can also be blank.
2	1	GAMMA	Unit weight for the current material.
3	1,2	CHAR(1)	One or two characters or one or two character strings beginning with the appropriate character, to designate the manner in which shear strengths are to be characterized. Conventional strengths (Options 1 through 5) require only a single character or character string; two-stage strengths are designated by a pair of characters or character strings. The acceptable characters or character strings and their interpretation are shown below. The key character(s) which must be input is(are) capitalized and underlined. (Note: Only the first non-blank character in each string is recognized and used.)

Character String	Interpretation
Conventional shear	Shear strengths are expressed by conventional Mohr-Coulomb parameters, c and ϕ or $\bar{c}$ and $\bar{\phi}$. Follow this line of data with Line 4A below.

(Continued)

Table 6 (Continued)

Input Line No.	Data Field No.	Variable/Description: Character String	Variable/Description: Interpretation
		Linear increase	Shear strengths increase linearly with depth below the profile line, starting at a prescribed value along the profile line. Follow this line of data with Line 4B below.
		Reference	Shear strengths increase linearly with depth below a specified reference elevation. Follow this line of data with Line 4C below.
		Anisotropic shear	Shear strengths vary with the orientation of the failure plane. Follow this line of data with Lines 4D below.
		Nonlinear Mohr-Coulomb envelope	The shear strength envelope is nonlinear. Follow this line of data with Lines 4E below.
		2-stage Linear strength envelopes	The shear strength is a "two-stage" strength where two sets of strength parameters are specified. Follow this line of data with Lines 4F below. (Applicable only when strengths are being entered for the second stage otherwise an error condition will result.)
		2-stage Nonlinear strength envelopes	The shear strength is a "two-stage" strength and the envelope(s) are not linear. Follow this line of data with Lines 4G below. (Applicable only when strengths are being entered for the second stage otherwise an error condition will result.)

(Continued)

Table 6 (Continued)

Input Line No.	Data Field No.	Variable/Description	
4A	1	COHESN	Cohesion value, c (or $\bar{c}$), for the soil.
4A	2	PHIANG	Angle of internal friction, ϕ (or $\bar{\phi}$), for the soil - in degrees.
4B	1	"CPROFL"	Value of shear strength along the profile line.
4B	2	"RATEIN"	Rate of increase in shear strength below the profile line, expressed as an increase in strength per unit of depth. (Units = force/length^2/length = force/length^3).
4C	1	"YDATUM"	Y coordinate for the "reference" elevation used as a datum for shear strengths.
4C	2	"CDATUM"	Value of shear strength at the reference elevation.
4C	3	"RATEIN"	Rate of increase in shear strength below the reference elevation, expressed as an increase in strength per unit of depth. (Units = force/length^2/length = force/length^3).
4D	1	FPANGL	Orientation of failure plane for set of shear strength values in Fields 2 and 3 - expressed as an angle, in degrees, measured from the horizontal - positive counterclockwise. Both negative and positive values are allowed; typically, values will range from -90° to +90°.
4D	2	COHESN	Cohesion value for current failure plane orientation.
4D	3	PHIANG	Angle of internal friction, ϕ (or $\bar{\phi}$) for current failure plane orientation - in degrees.
		Repeat Line 4D for additional anisotropic shear strength values in a sequence of increasing angles of failure plane orientation. More than one set (3 values) of data can be entered on a given line; however, each line must contain integer multiples of three values, comprising complete data sets. Input a blank line to terminate the current anisotropic shear strength data and then continue with Line No. 5.	

(Continued)

Table 6 (Continued)

Input Line No.	Data Field No.	Variable/Description	
4E	1	"SIGMA"	Normal stress, σ(or $\bar{\sigma}$), for point which is being defined on nonlinear failure envelope.
4E	2	"TAU"	Shear stress, τ , for point on nonlinear envelope.
	Repeat Line 4E for additional values to define a nonlinear failure envelope. Values must be input in a sequence of increasing values of normal stress. More than one pair of values (σ and τ) can be entered on a single line of input data if desired. Input a blank line to terminate the current nonlinear failure envelope data and continue with Line No. 5.		
4F	1	COHESN	Intercept (d_R) for the envelope of τ_{ff} vs. $\bar{\sigma}_{fc}$ from isotropically consolidated-undrained triaxial compression tests.
4F	2	PHIANG	Slope (ψ_R) for the envelope of τ_{ff} vs. $\bar{\sigma}_{fc}$ from isotropically consolidated-undrained triaxial compression tests.
4F	3	COHESN	Effective stress cohesion value ($ds = \bar{c}$) for envelope from consolidated-drained (S) or consolidated-undrained with pore pressure measurement (R) shear tests.
4F	4	PHIANG	Effective stress angle of internal friction ($\psi_s = \bar{\phi}$) for envelope from consolidated-drained (S) or consolidated-undrained with pore pressure measurement (R) shear tests.
4G	1	"SIGMA"	Effective normal stress on the failure plane at consolidation ($\bar{\sigma}_{fc}$) for nonlinear two-stage envelope.
4G	2	"TAUFF"	Shear stress on the failure plane at failure (τ_{ff}) for the envelope derived from isotropically consolidated-undrained triaxial compression tests at $\bar{\sigma}_{fc}$.

(Continued)

Table 6 (Continued)

Input Line No.	Data Field No.	Variable/Description	
4G	3	"TAUFF"	Shear stress on the failure plane at failure (τ_{ff}) for the conventional effective stress (S) failure envelope (derived either from consolidated drained tests or consolidated-undrained shear tests with pore water pressure measurements) at $\bar{\sigma}_{fc}$.
		Repeat Line 4G for additional values to define the complete nonlinear envelopes for the two-stage strengths. Values must be entered in a sequence of increasing values of normal stress. More than one set of values (points) may be entered on a single line of input data if desired; however, each line must contain integer multiples of three values, comprising complete data sets (points). Input a blank line to terminate the current nonlinear failure envelope data and proceed with Line No. 5 of input data for the current material.	
5	1 and 2	(CHAR)	Two characters separated by blanks, or two character strings separated by blanks, to designate how pore water pressures are to be defined for this material. The acceptable characters or character strings and their interpretation are shown below. The key characters which must be input are capitalized and underlined. (Note: Only the first character of any character string is recognized and used.)

Character String	Interpretation
<u>N</u>o pore pressure	Pore pressures are zero. (Only one character, N , is actually required in this case.) No Line 6 is required; see notes following Line No. 6.
<u>C</u>onstant <u>P</u>ore pressure	Pore pressures are constant. Follow this line of data with Line No. 6 giving the value of the pore water pressure.

(Continued)

Table 6 (Continued)

Input Line No.	Data Field No.	Variable/Description		
		Character String	Interpretation	
		Constant Ru	The value of the pore water pressure coefficient, r_u, is constant. Follow this line of data with Line No. 6 giving the value of the pore water pressure coefficient, r_u.	
		Piezometric Line	A piezometric line is used to define pore water pressures in this material. Follow this line of data with Line No. 6 giving the identification number of the piezometric line which is to be used. Note: Group D data must eventually be input.	
		Interpolate Pore water pressure	Pore water pressures are to be determined by interpolation of values of pore water pressure. Note: Group E data must eventually be input, but no Line No. 6 is required below. See notes following Line No. 6.	
		Interpolate Ru values	Pore water pressures are to be determined by interpolation of values of the pore water pressure coefficient, r_u. Note: Group E data must eventually be input, but no Line No. 6 is required below.	
5	3	CHAR(3)	A character or character string to designate if negative pore water pressures are to be acceptable in this material. Specify "N" (i.e., "Negative") if negative pore pressures are acceptable. Any other character (or blank) in this field will cause negative pore water pressures to be set to zero.	

(Continued)

Table 6 (Concluded)

Input Line No.	Data Field No.	Variable/Description	
6	1	Optional	Value of (1) the pore water pressure, or (2) r_u , or (3) the identification number of the piezometric line depending on data on Line No. 5. Line 6 is not required in all cases and in such cases should be omitted.
		Repeat Lines 1 through 6, as sets, for data for additional material types. Material types may be input in any order. (Material type numbers, MTYPE, may actually be missing from a sequence; however, there appears to be little need for omitting numbers from a sequence.) Input a blank line after data for the last material have been input to terminate all Group C data; then return to input of Command Words.	

Group D - Data for the Piezometric Line (Optional)

45. The Group D data consist of the data for the piezometric lines. These data are required only when the material property data (see paragraphs 35 through 44) have designated that the pore water pressures in one or more materials are to be defined by a piezometric line.

46. The computer program allows several piezometric lines to be defined. The number of lines depends on the size of arrays as given in Appendix A. Each piezometric line is assigned an identification number in the range of from 1 to the maximum number of piezometric lines allowed. The identification number is used with the material property data to associate a given piezometric line with a given material (See Table 6 - Line No. 6). Several materials may share and use the same piezometric line. The sequence and pattern for assigning numbers to piezometric lines is arbitrarily selected by the user.

47. Each piezometric line is defined by the coordinates of a series of points from left to right along the line. The points are assumed to be connected by straight lines to form a continuous, piece-wise linear piezometric surface. Vertical segments of the piezometric lines are acceptable.

48. Pore water pressures are calculated by taking the vertical distance between any point of interest and the corresponding point on the piezometric line and multiplying the distance by the unit weight of water (or other fluid). The unit weight of water (or other fluid) may be input with the piezometric line data (if different from 62.4) and may be different for each piezometric line. A unit weight of 62.4 will be assumed for any line for which a unit weight is not input. Pore pressures are considered to be negative above the piezometric line and positive below the piezometric line (See Table 6 - Line No. 5, Field No. 3 - regarding negative pore water pressures).

49. Group D data for the piezometric line may be input in either the Normal Mode or Modify Mode. The forms for data input in the Normal and Modify Modes are presented in Tables 7 and 8, respectively.

50. For multi-stage stability computations piezometric line data may need to be entered for the first and the second or third stages[1]. Data entry is the same for the first and the second or third stages; the stage for which data are currently being entered is designated by the Command Words, FIR and SEC (See paragraphs 22 through 26).

[1] For materials with strength Options 1 through 5 the piezometric line data entered for the second stage will be used for the second stage computations. For materials which use "two-stage" strengths (Strength Options 6 and 7), the piezometric line data specified with the second stage data will only actually be used for the third-stage computations; they will be ignored if only two stage computations are performed.

Table 7

Group D - Piezometric Line Data Input Format - Normal Mode

Input Line No.	Data Field No.	Variable	Description
1	1	PZLINE	Number used to identify the piezometric line. Any value from unity (1) through the maximum number of piezometric lines. The maximum number of piezometric lines allowed is equal to MAXPZL. (see Appendix A).
1	2	GAMMAW	Unit weight of water or other fluid, to be used with this piezometric line - optional. If this vale is omitted, a value of 62.4 is assumed.
1	2 or 3	LABEL	Any alphanumeric character(s) or character string(s) to be written on the output file as a label for current the piezometric line - optional. Must not start with a numeral (1, 2, 3 etc.) - this is required to distinguish if information in the second field is the unit weight of fluid or this label. Can be up to a maximum of 30 characters and/or blanks and must fit on an 80-column line (including Fields 1 and 2). Can also be blank.
2	1	XPIEZL	X coordinate of point on the piezometric line which is currently being defined.
2	2	YPIEZL	Y coordinate of point on the piezometric line which is currently being defined.

Repeat Line(s) 2 for additional points on the piezometric line in a left-to-right (increasing x value) sequence. Vertical segments are allowed. More than one pair of coordinates (XPIEZL, YPIEZL) may be entered on a given line of input data if desired. Input a blank line to terminate data for the current piezometric line. The maximum number of points allowed on a given piezometric line is equal to MAXPZP. (See Appendix A).

Repeat Lines 1 and 2, as sets, for additional piezometric lines. Lines may be input in any order. (Line numbers, PZLINE, may be missing from a sequence; however, there appears to be little need for omitting numbers from a sequence). Input two blank lines after the last line of non-blank piezometric line data to terminate all Group D data and return to input of Command Words. The first blank line terminates the last piezometric line data set and the second blank line terminates the Group D data. The maximum number of piezometric lines allowed is equal to MAXPZL. (See Appendix A).

Table 8

Group D - Piezometric Line Data Input Format - Modify Mode

Input Line No.	Data Field No.	Variable	Description
1	1	NLINE	Number of the existing piezometric line for which coordinate is to be changed.
1	2	NPOINT	Number of the existing point on the designated piezometric line where the coordinate is to be changed.
1	3	XPIEZL	X coordinate of point on the piezometric line which is currently being defined.
1	4	YPIEZL	Y coordinate of point on the piezometric line which is currently being defined.

Repeat Line(s) 1 for additional points whose coordinates are to be changed in Modify Mode. More than one set of data (4 quantities) may be entered on a given line; however, each line must contain integer multiples of 4 quantities, comprising complete data sets. Input a single blank line to terminate all Group D data and return to input of Command Words.

Group E - Data for Pore Water Pressure Interpolation (Optional)

51. The Group E data consist of a series of discrete values of either pore water pressure (u) or pore water pressure coefficient (r_u). The values are specified at selected points and used to interpolate pore water pressures at desired points along the shear surface. These data are required only when the material property data (paragraphs 35 through 44) have designated that the pore water pressures in one or more materials are to be defined by interpolation. The procedure used for interpolation of pore water pressures is based on the procedure proposed by Chugh (1981) and appears to be an improvement over the interpolation procedure formerly employed by Wright (1982). The interpolation procedure is briefly described below.

Interpolation Procedure

52. Pore water pressures are interpolated at a point corresponding to the center of the base of each vertical slice (see paragraphs 79 through 132 regarding slices). The interpolation is carried out slice-by-slice for each slice whose base lies in a material where the pore pressure interpolation option was specified. The interpolation is initiated by locating the closest points to the point of interest (center of base of slice) which lies in each of the four quadrants surrounding the point of interest. The four quadrants are illustrated schematically in Figure 2. Once the closest points in each of the four quadrants are located, three of the four points are then selected (arbitrarily) and used to evaluate the coefficients a, b, and c in a linear interpolation function of the form

$$u = a + bx + cy \tag{5}$$

where u is the pore water pressure, x and y represent the coordinates of the point where the pore water pressure (u) exists, and a, b, and c are interpolation coefficients. Equation 5 is solved for the interpolation coefficients (a, b, and c) using the known pore water pressures and corresponding coordinates of the three selected points. The values of the coefficients are next used in Equation 5 to calculate the pore water pressure at the center of the base of the slice. This process is then repeated using another combination of three of the four points found previously and a new set of calculations is

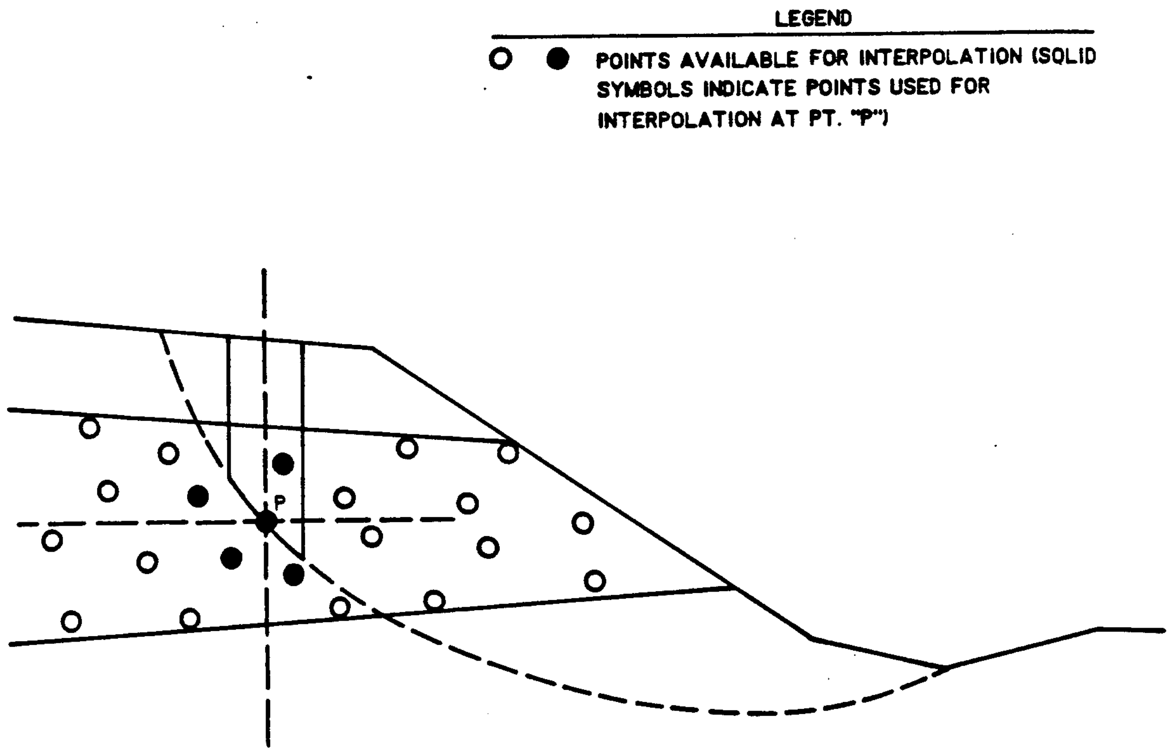


Figure 2. Illustration of pore pressure points used for interpolation

performed to calculate the pore water pressure at the center of the base of the slice. This sequence of calculations is performed a total of four times, each time using a different combination of three of the four points. Finally, after four values of pore water pressure have been determined by interpolation, the four values are averaged arithmetically, and the average value is used for the slice. This process is repeated for each slice (and each shear surface) where pore water pressures are to be calculated by interpolation.

53. In the case where the pore pressure coefficient, r_u, rather than the pore water pressure is to be used for interpolation, the same procedures as those described above are used, except that u is replaced by r_u. Once an average value of r_u for the center of the base of the slice is obtained by interpolation, the average value is used to calculate the pore water pressure. Thus, the computer program interpolates r_u first, and then calculates the pore water pressure, rather than calculating u first, and then interpolating values of u to the base of the slice.

Form of Data Input

54. The Group E data must immediately follow the Command Word "INT" (for "INTERPOLATION DATA"). The data may be input in either the Normal Mode or the Modify Mode. The forms of input for the Normal and Modify Modes are presented in Tables 9 and 10, respectively.

Table 9

Group E - Pore Pressure Interpolation Data Input Format - Normal

Input Line No.	Data Field No.	Variable/Description	
1	1	CHAR	A single character, or a character string starting with the appropriate character, to designate if the data which will follow (on Line 2) represent values of pore water pressure or values of the dimensionless pore pressure coefficient, r_u. The character should be either "P" to indicate that values represent pore water pressure, or "R" to indicate that values represent values of r_u. A blank line is interpreted to represent the end of all Group E data.
2	1	XINTPT	X coordinate for interpolation point.
2	2	YINTPT	Y coordinate for interpolation point.
2	3	UINTPT	Value of pore water pressure coefficient, r_u, (depending on designation on Line No. 1), at the specified coordinate point.
2	4	MINTPT	Material type (with reference to Group C data) for which this specified pore pressure information is to be used. If zero, this information (point) will be used for all materials where pore pressures are interpolated, provided that the type of data (pore pressures or r_u at this point is consistent with what was indicated by the material data, e.g., if r_u values are to be interpolated, this line of data must contain an r_u value or it will not be used.
		Repeat Line(s) 2 for additional points with data of a similar type (i.e., pore pressure or r_u). More than one set (4 quantities) of data may be entered on a given line of input data. However, each line of input must contain an integer multiple of four values, comprising complete sets of data. Input a blank line to terminate data of one type (pore pressure or r_u), then follow with another line 1. The data on Line 1 following the above Line(s) 2 may either designate another type of data (i.e., pore pressure vs. r_u) and be followed by more Line(s) 2, or may serve to terminate all Group E data.	

Table 10

Group E - Pore Pressure Interpolation Data Input Format - Modify Mode

Input Line No.	Data Field No.	Variable/Description	
1	1	CHAR	A single character, or a character string beginning with the appropriate character, to designate whether the data which are to follow are to replace existing data, or are to be added to existing data. The character should be either an "R", to indicate that values are to be replaced, or an "A", to indicate that values are to be added. If the character is R, proceed with Line(s) 2A to replace data; if the character is A, proceed with Lines 2B and 3 to add data. A blank character (blank line) is interpreted as the end of all Group E data designated by the current Command Word.
2A	1	NPOINT	Number identifying the number of the point which is to be replaced. (On previous input the first point input was assumed to be Point No. 1, the second input was assumed to be Point No. 2, etc.).
2A	2	XINTPT	New X coordinate for point which is being replaced.
2A	3	YINTPT	New Y coordinate for point which is being replaced.
2A	4	UINTPT	New value of either pore water pressure or r_u at point which is being replaced. Note: The type of value (pore pressure or r_u) must be the same as it was originally at this point.
		Repeat Line(s) 2A for additional points which are to be replaced. More than one set (4 values) of data may be entered on a given line of input data if desired; however, each line of input must contain an integer multiple of four values, comprising complete sets of data. Input a blank line to terminate Line(s) 2A, then proceed with Line 1 again.	

(Continued)

Table 10 (Concluded)

Input Line No.	Data Field No.	Variable/Description	
2B	1	CHAR	A single character, or a character string beginning with the appropriate character, to designate whether the data which are to follow represent values of pore water pressure or values of the dimensionless pore water pressure coefficient, r_u. The character should be either a "P", to indicate that values represent pore water pressure, or an "R", to indicate that values represent values of r_u. A blank line <u>is not allowed</u> here.
3	1	XINTPT	X coordinate for interpolation point.
3	2	YINTPT	Y coordinate for interpolation point
3	3	UINTPT	Value of pore water pressure or pore pressure coefficient, r_u (depending on designation on Line 2B), at the specified coordinate point.
3	4	MINTPT	Material type (with reference to Group C data) for which this specified pore pressure information is to be used. If zero, this information (point) will be used for all materials where pore pressures are interpolated, provided that the type of data (pore pressures or r_u) at this point is consistent with what was indicated by the material data, e.g., if r_u values are to be interpolated, this line of data must contain an r_u value or it will not be used.

Repeat Line(s) 3 for additional points with <u>data of a similar type</u> (e.g., pore pressure or r_u), which are to be added. More than one <u>set</u> (4 values) of data may be entered on a given line of input data if desired; however, each line of input must contain an integer multiple of four values, comprising complete <u>sets</u> of data. Input a blank line to terminate data of one type (pore pressure or r_u), then proceed with Line 1 again.

Group F - Data for the Slope Geometry (Optional)

55. The Group F data are used to define (optionally) the slope geometry. As discussed in paragraphs 28 through 34 with the profile lines, the slope geometry data permit several different slope geometries to be "cut" in a given profile (set of profile lines); any soil in the profile which lies above the surface defined by the slope geometry data is ignored. Thus, several slope geometries may be considered by simply changing the slope geometry (Group F) data.

56. Slope geometry data are also used to cancel a previous set of slope geometry when new profile line data are entered and it is desired to have new slope geometry generated (from the new profile line data). In such cases a "null" set of slope geometry data should be entered as described later in this section.

Description of Data

57. The slope geometry data define the surface profile of the slope and consist of the coordinates of a series of points from left-to-right along the surface of the slope. The points are assumed to be connected by straight lines to form a continuous slope profile. All material (soil, rock, etc.) which has been defined by profile lines to exist above the surface of the slope, designated by the slope geometry data in Group F, is ignored. Thus, profile lines specified in Group B could define an original soil profile, and the slope geometry data could describe one or more excavated slope profiles within the original soil profile.

58. Both left and right facing slopes are allowed, and a single slope may contain both a left and a right face in its specified geometry. Vertical "slopes" and horizontal "slopes" are also allowed. In the case of a horizontal "slope" loads would be applied by surface pressures and the problem becomes essentially one of bearing capacity.

Special Note for Flat Slopes

59. Special care is required when using the computer program with either very flat or horizontal slopes. The computer program determines the direction (left or right) of potential sliding by comparing the elevations of the two ends of the shear surface. If the left end is higher than the right end, the direction of potential sliding is assumed to be to the right for the specific shear surface examined. Otherwise the direction of potential sliding is

assumed to be to the left. Thus, for horizontal slopes the direction of sliding is assumed to be to the left. Accordingly, for horizontal "slopes" shear surfaces should be directed to the left of the area of the applied surface loading. For flat, but not horizontal, slopes the direction of sliding is assumed to be in the direction in which gravity would produce sliding, i.e., from high to low. If sliding in the opposite direction from gravity were possible due to relatively high surface pressures, special features of the program would have to be invoked. Specifically, a special "opposite sign convention option" must be activated by optional data in the Group H - Analysis/Computation data (See Table 15 - Sub-Command Word "OPP").

Form for Data Input

60. The Group F data must immediately follow the Command Work "SLO" (or "SLOPE GEOMETRY"). The data may be input in either the Normal or Modify Modes. The forms of input for the Normal and Modify Modes are presented in Tables 11 and 12, respectively.

61. A "null" set of slope geometry data is entered by first activating slope geometry data input by the Command Word "SLO". The slope geometry data are then immediately terminated by a blank line, i.e., no coordinates are actually entered.

Table 11

Group F - Slope Geometry Data Input Format - Normal Mode

Input Line No.	Data Field No.	Variable/Description	
1	1	XSLOPE	X coordinate of slope point.
1	2	YSLOPE	Y coordinate of slope point.
		Repeat Line(s) 1 for additional points on the surface of the slope from left-to-right. More than one pair of coordinates (XSLOPE, YSLOPE) may be entered on a given line of input data if desired. Input a blank line to terminate slope geometry data (all Group F data); then return to input of Command Words. If only a blank line, not preceded by x and y coordinates, is input, the slope geometry data are canceled, i.e., a null set of data are input. When slope geometry data are canceled new coordinates defining the slope geometry will be computed by the computer program using the profile line data.	

Table 12

Group F - Slope Geometry Data Input Format - Modify Mode

Input Line No.	Data Field No.	Variable/Description	
1	1	N	Number of slope point whose coordinates are to be changed.
1	2	XSLOPE	New X coordinate for the point.
1	3	YSLOPE	New Y coordinate for the point.
		Repeat Line 1 for points whose coordinates are to be changed. More than one set of data (3 quantities) may be entered on a given line; however, each line must contain integer multiples of 3 quantities, comprising complete data sets. Input a blank line to terminate current slope geometry data in Modify Mode; then return to input of Command Words.	

Group G - Data for Surface Pressures (Optional)

62. Group G data consist of the "Surface Pressures" which are used to define stresses acting on the surface of the slope. When two-stage or three-stage computations are being performed, different sets of surface pressures may be specified for each stage. Values specified for one stage are not used for the other stage of two-stage computations.

63. Surface pressures are specified in terms of values of stress acting normal (perpendicular) to the slope and tangential (parallel) to the slope. The pressures are specified in the input data by specifying coordinates of points on the surface of the slope and the corresponding values of normal and shear stress at the point. Points are specified in a left-to-right sequence. The pressures are assumed to be zero to the left of the first point specified and zero to the right of the last point specified. The normal and shear stresses are assumed to vary linearly between specified points. If an abrupt change in stress occurs at a point, the coordinates of the point should be entered twice, first with the value of stress just to the left of the point and then with the value of the stress just to the right of the point.

64. Compression is considered to be positive for the normal stresses acting on the surface of the slope; tension is considered to be negative. The shear stresses are considered to be positive when they act to the right and negative when they act to the left.

65. The coordinates of points which are input to define the surface pressures should be specified as precisely on the surface of the slope as is practically possible. If the points do not coincide with the surface of the slope an error condition may result and computations will be abandoned with an appropriate warning message.

66. <u>Surface pressures cannot be specified (input) on vertical segments of the slope</u>, because surface pressures are considered to produce loads on the tops of vertical slices. Loads on the vertical sides of slices are considered to be either included in side forces, which are computed as unknowns, or specified as concentrated forces, which are considered to be known.

67. Surface pressure data must immediately follow the Command Word "SUR" (or "SURFACE PRESSURES"). The data may be input in either the Normal or

Modify Modes. The forms of input for the Normal and Modify Modes are presented in Tables 13 and 14, respectively.

Table 13

Group G - Surface Pressure Data Input Format - Normal Mode

Input Line No.	Data Field No.	Variable/Description	
1	1	XSURFP	X coordinate value of point where stress acts.
1	2	YSURFP	Y coordinate value of point where stress acts.
1	3	PNORML	Normal stress at point.
1	4	PSHEAR	Shear stress at point.

Repeat Line(s) 1 for additional points to define the surface pressures in a left-to-right sequence. More than one set of data (4 quantities) may be entered on a given line; however, each line must contain integer multiples of 4 quantities, comprising complete data sets. Input a blank line to terminate the surface pressures data (all Group G data); then return to input of Command Words (paragraphs 22 through 26). The maximum number of surface pressure points allowed is equal to MAXSUP. (See Appendix B).

Table 14

Group G - Surface Pressure Data Input Format - Modify Mode

Input Line No.	Data Field No.	Variable/Description	
1	1	N	Number of the point where the coordinates and/or the surface pressure are to be changed.
1	2	XSURFP	X coordinate value of point where stress acts.
1	3	YSURFP	Y coordinate value of point where stress acts.
1	4	PNORML	Normal stress at point.
1	5	PSHEAR	Shear stress at point.

Repeat Line(s) 1 for additional points to modify previously defined surface pressure data. Not all points need to be modified. More than one set of data (5 quantities) may be entered on a given line; however, each line must contain integer multiples of 5 quantities, comprising complete data sets. Input a blank line to terminate the surface pressure data in Modify Mode; then return to Command Words (paragraphs 22 through 26).

Group H - Data for Concentrated Forces (Optional)

68. Group H data consist of the "Concentrated Forces". Concentrated Forces consist of forces which act at any point externally or internally within the slope. When two-stage or three-stage stability computations are being performed, different sets of concentrated forces may be specified for each stage. Values specified for stage one are not used for the stages two and three computations.

69. Concentrated forces are specified in terms of the coordinates at which the force acts and the value of the force. The actual force can be specified in two ways: (1) the separate horizontal (x) and vertical (y) components of the force can be specified, or (2) the magnitude of the force and its inclination from the horizontal can be specified. If the components of the force are specified, positive values are considered to act to the right and upward (in the direction of positive values of the coordinates). If the magnitude and inclination of the force are specified, the magnitude is generally specified as positive. The direction is then specified as an angle measured from the horizontal and considered to be positive in the counterclockwise direction. Negative angles are assumed to be clockwise from the horizontal direction. If the magnitude of the force is positive and the angle is zero degrees (0°), the force acts horizontally to the right. If the angle is ± 180°, the force acts to the left. If the magnitude of the force is positive and the angle is 90°, the force acts vertically upward. If the angle is -90° (or + 270°), the force acts vertically downward. Negative values for the magnitude of the force correspond to a force acting in the direction opposite to the directions described for positive forces. Thus, a positive force acting at an inclination of 0° is identical to a force of the same magnitude, but negative, acting at ± 180°.

70. Concentrated forces can be specified anywhere; there is no illegal location. During computations the program checks to determine if any concentrated force that was specified is located within any slice. If it is, the force is added to the other forces acting on that slice. If a concentrated force lies outside the limits of all slices, it is ignored for the particular shear surface where this occurs.

71. Concentrated force (Group H) data must immediately follow the Command Word "FOR" (or "FORces"). The data may only be input in Normal Mode; Modify Mode has no effect on entry of Concentrated Force data. The input format for the Concentrated Forces is presented in Table 15.

72. Concentrated forces are numbered for reference purposes. Any numbering sequence may be used, but the numbers must be in the range of from 1 to the maximum number of concentrated forces allowed by the program (see Appendix B). Once a set of concentrated forces has been entered and some computations have been performed, any individual concentrated force may be altered and new computations may be performed. To alter forces new data are simply entered for the forces (based on the reference number assigned to the force in the input data).

Table 15

Group H - Concentrated Force Data Input Format

Input Line No.	Data Field No.	Variable/Description	
1	1	NCONCF	Number used to identify the concentrated force being specified on this line of data.
1	2	XCONCF	X coordinate value of point where force acts.
1	3	YCONCF	Y coordinate value of point where force acts.
1	4	CONCF1	Horizontal component of the force/OR/magnitude of the force, depending on the option designated in Field No. 6 of this line of data.
1	5	CONCF2	Vertical component of the force/OR/ inclination of the force, measured in degrees from the horizontal, depending on the option designated in Field No. 6 of this line of data.
1	6	CFOPTN	Option for the concentrated force, as follows: = 1 if the horizontal and vertical components of the force are being specified. = 2 if the magnitude and direction (inclination) of the resultant force is being specified.

Repeat Line(s) 1 for additional concentrated forces. More than one set of data (6 quantities) may be entered on a given line of input data; however, each line must contain integer multiples of 6 quantities, comprising complete data sets. Input a blank line to terminate the concentrated force data (all Group H data); then return to input of Command Words (paragraphs 22 through 26). The maximum number of concentrated forces allowed is equal to MAXCNF. (See Appendix B.)

Group J - Data for Reinforcement Lines (Optional)

73. Group J data are used to specify individual lines of reinforcement within the slope cross-section. The reinforcement lines are defined by specifying coordinates along the lines in the same manner as is done for soil profile lines. Longitudinal and transverse components are defined for each reinforcement line. The values of these forces in units of force/unit length into the cross-section are specified at each coordinate point along the reinforcement line; the forces are assumed to vary linearly between specified points. Points are assumed to be connected by straight lines such that the reinforcement is considered to be a piece-wise linear feature in the cross-section. The reinforcement is considered to produce in-ternal forces in the soil mass only; the reinforcement is not assumed to have any weight or to occupy any physical space in the cross-section, i.e., it is assumed to be infinitesimally thin.

74. The longitudinal forces in the reinforcement are considered to be positive when they are tensile; compressive forces are considered to be negative. The shear forces are considered to be positive when they act such that they produce a counter-clockwise moment on the adjoining reinforcement as shown in Figure 3.

75. The reinforcement data are used to compute forces acting on the shear (sliding) surface. When the base of a particular slice crosses the reinforcement, a force is calculated and applied as a known force to the base of the slice. This force is considered to be a force in the reinforcement, acting in addition to forces carried by the soil. Other, separate forces are assumed to act on the base of the slice to represent the forces in the soil. The orientation of the reinforcement force on the base of a slice is determined by the orientation of the reinforcement and an additional parameter (ROTMAX) representing a maximum rotation (reorientation) of the reinforcement due to deformation. The reorientation parameter, ROTMAX, represents an angle that the reinforcement rotates through from its initial, specified, orientation. If the angle is specified as zero (0.0), the reinforcement is assumed to be oriented in the original direction(s) of the reinforcement. If the angle is greater than zero, the reinforcement is assumed to be rotated through

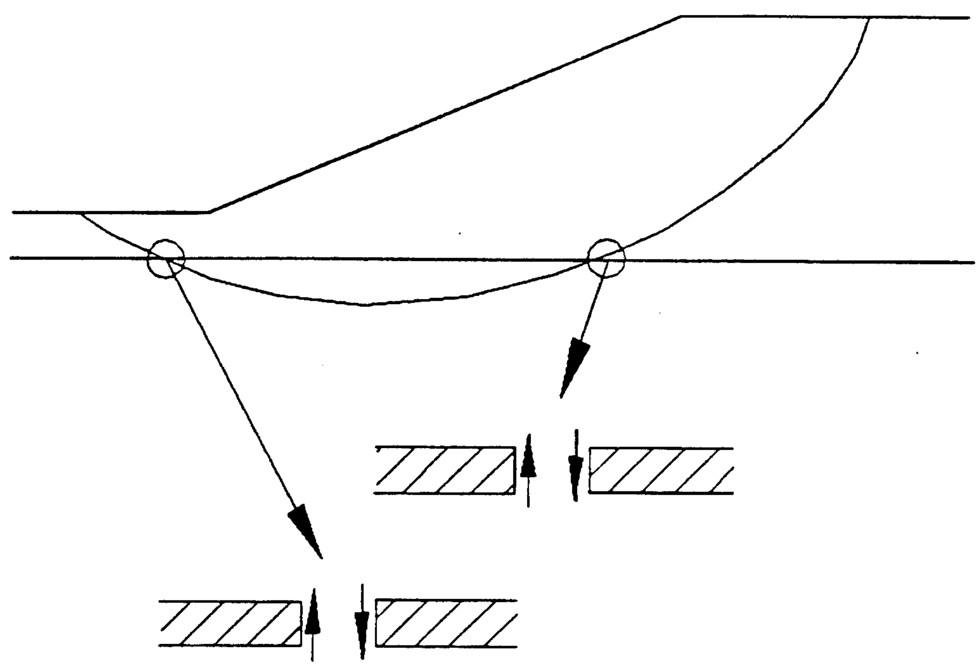


Figure 3. Direction for positive shear forces in reinforcement

the specified angle, but not past the point where it becomes tangent to the shear surface. The direction that the reinforcement is assumed to be rotated depends on the direction in which the slope faces, as shown in Figure 4. The directions of rotation shown in Figure 4 (up slope) correspond to positive rotation angles, negative rotation angles produce rotations in the opposite directions. For horizontal ground, the rotation is assumed to be the same as that for a left-facing slope, i.e., counter-clockwise rotation of the reinforcement is considered to be positive.

76. Reinforcement forces are treated in the stability computations in either of two ways: In the first way, Option 1, the reinforcement forces are calculated and applied to the boundaries between each slice as well as to the base of the slice, as described above (Figure 5). In the second way, Option 2, the reinforcement forces are applied only to the base of the slice on which they act (Figure 6). The system of forces shown in Figures 5 and 6 are statically equivalent and differ only in how the reinforcement forces are distributed among slices. When forces are applied to the boundaries between slices they are calculated from the forces in the reinforcement at the point where the reinforcement crosses the slice boundary. Equal and opposite forces are applied to the two slices on each side of a given boundary. The way that the reinforcement forces are applied is designated in the input data for each reinforcement line. An option (REOPTN) is specified to designate if the forces are to be applied both internally and on the base of the slice (Option 1 - Figure 5) or only on the base of the slice (Option 2 - Figure 6). Option 1 is the default value used by the program if Option 2 is not specified.

77. Depending on how the reinforcement forces are applied, the side forces between slices will have different meanings. If the reinforcement forces are applied between slices (Option 1), the side forces will represent only the forces transmitted directly through the soil. If the reinforcement forces are applied only to the base of the slices (Option 2), the side forces will represent the forces in the soil, plus the reinforcement forces.

78. Group J data must immediately follow the Command Word "REI" (or "REINFORCEMENT LINES"). The data may be input in either the Normal Mode or the Modify Mode. Input for the Normal Mode is described in Table 16; input for the Modify Mode is described in Table 17.

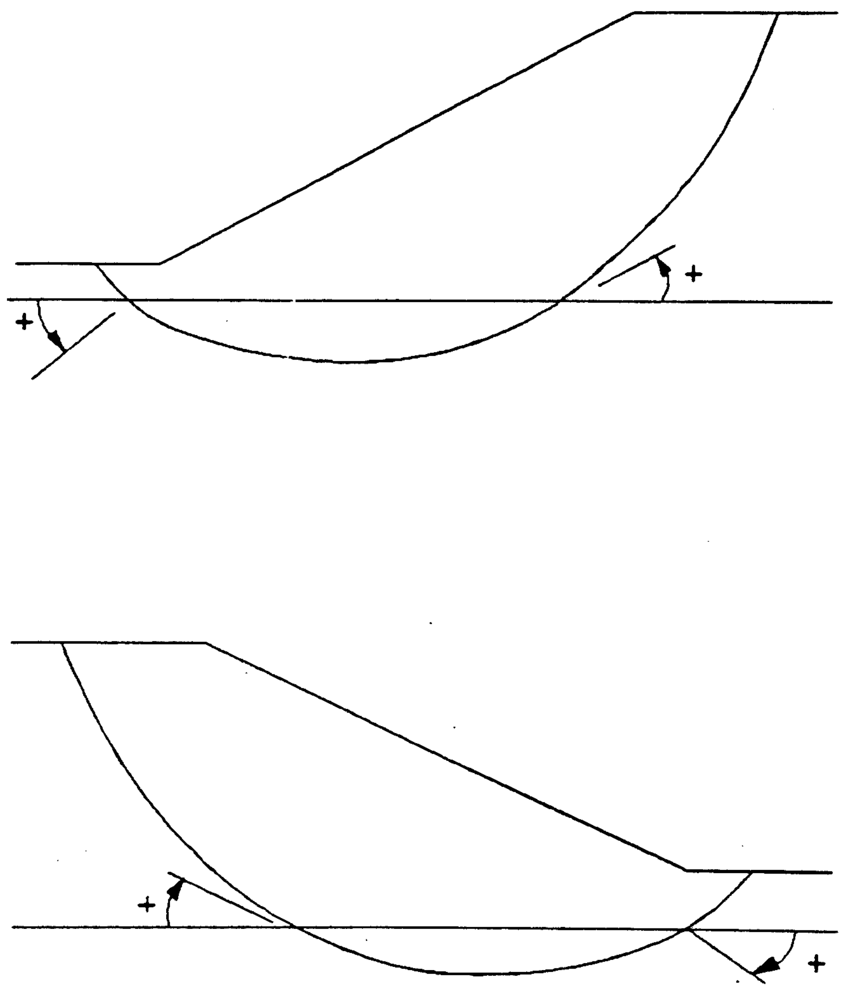


Figure 4. Direction for positive rotations in reinforcement

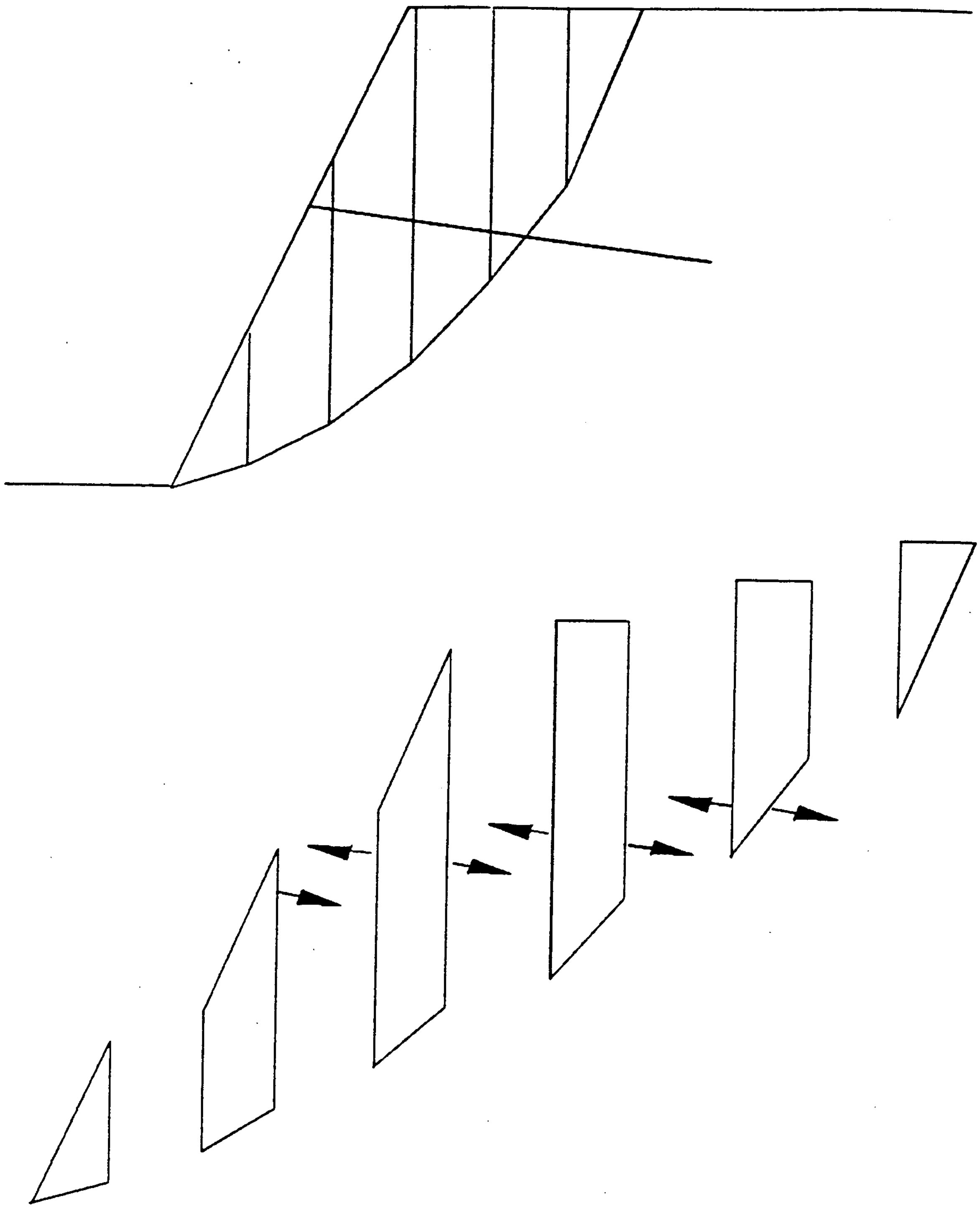


Figure 5. Reinforcement forces applied to slices when Option (REOPTN) = 1

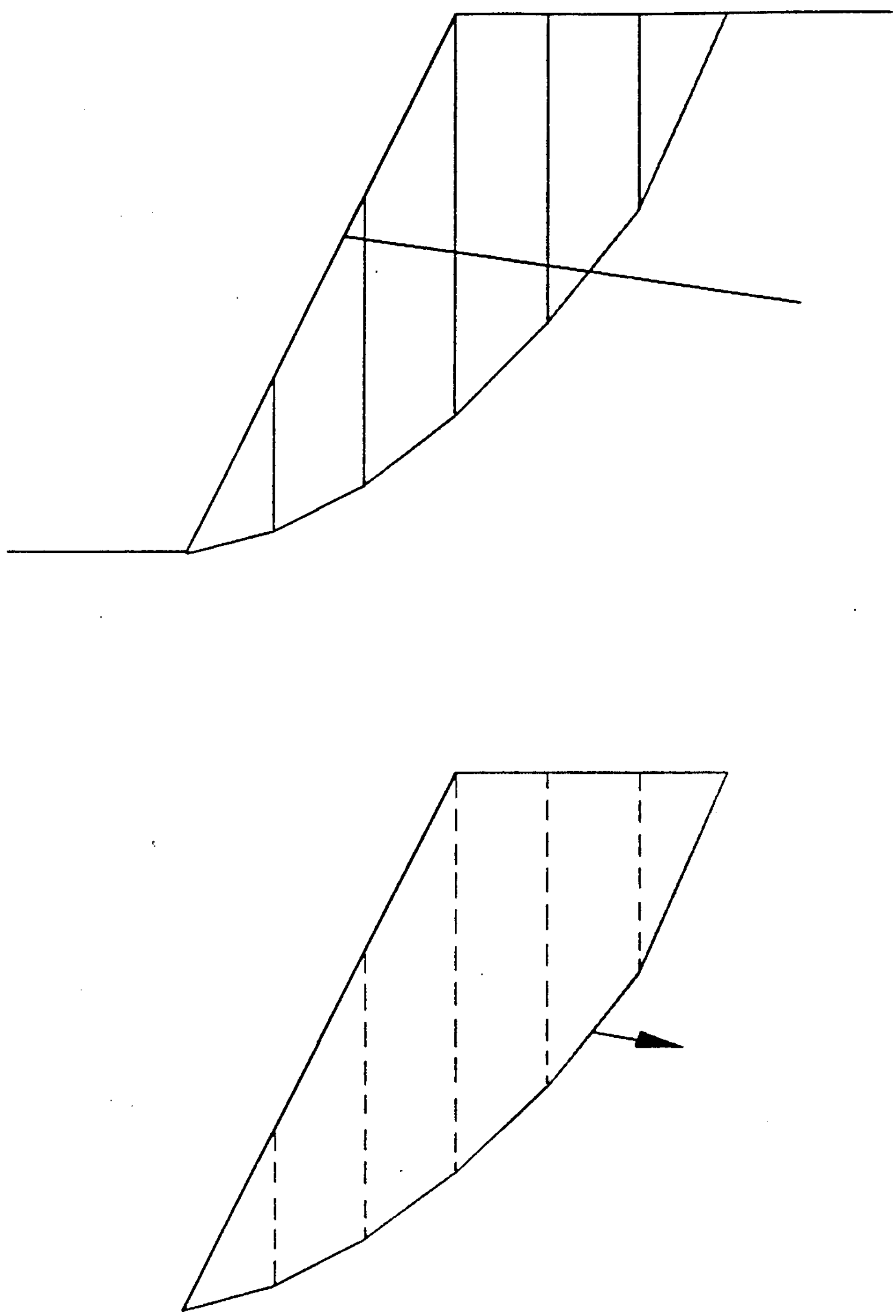


Figure 6. Reinforcement force applied to slice when Option (REOPTN) = 2

Table 16

Group J - Reinforcement Line Data Input Format - Normal Mode

Input Line No.	Data Field No.	Variable	Description
1	1	NLINE	Number of the reinforcement line to be defined next, i.e., on Line(s) 2 below. Any sequence for numbering and input of reinforcement lines may be used. The maximum number of reinforcement lines allowed is equal to MAXRFL. (See Appendix B).
1	2	ROTMAX	Maximum reinforcement rotation angle (in degrees). If this field is left blank, a value of zero degrees (0.0°), i.e., no rotation is assumed. A value must be entered in this field if the option in field 3 of this line of data is to be entered.
1	3	REOPTN	A number (either 1 or 2) used to designate how the reinforcement forces are to be applied to slices in the stability computations, as follows: = 1 if the forces are to be applied to the boundaries between slices as well as to the base of slices. = 2 if the forces are only to be applied to the slice base crossed by reinforcement. If this Field is left blank (empty), Option 1 is assumed.
2	1	XREINP	X coordinate of point on the reinforcement line currently being defined.
2	2	YREINP	Y coordinate of point on the reinforcement line currently being defined.
2	3	LREINP	Longitudinal (axial) force (units of force per unit length into the cross-section) in the reinforcement at the current point. Tensile forces are positive; compressive forces are negative.

(Continued)

Table 16 (Concluded)

Input Line No.	Data Field No.	Variable/Description
2	4	TREINP Transverse (shear) force (units of force per unit length into the cross-section) in the reinforcement at the current point. Shear forces are positive when they produce a counter-clockwise moment on the reinforcement.
		Repeat Line(s) 2 for additional points on the reinforcement line in a left-to-right sequence. More than one set of values (XREINP, YREINP, LREINP, TREINP) may be entered on a given line of input data; however, each line of data must contain integer multiples of four quantities, comprising complete data sets. A blank line must be entered to terminate data for the current reinforcement line. The maximum number of points allowed on a reinforcement line is equal to MAXRLP. (See Appendix B).
		Repeat Lines 1 and 2, as sets, for additional reinforcement lines. Lines may be input in any order. (Line numbers, NLINE, may also be missing from a sequence; e.g. line numbers 1, 2, 6, and 7 might be used.) TWO (2) blank lines must be entered after the last non-blank line of reinforcement data to terminate ALL Group J data and return to input of Command Words. The maximum number of reinforcement lines allowed is equal to MAXRFL. (See Appendix B).

Table 17

Group J - Reinforcement Line Data Input Format - Modify Mode

Input Line No.	Data Field No.	Variable	Description
1	1	NLINE	Number of the existing reinforcement line for which coordinates or values of forces are to be changed.
1	2	NPOINT	Number of the point on the reinforcement line where coordinates or values of forces are to be changed.
1	3	XREINP	New value of the X coordinate for point designated.
1	4	YREINP	New value of the Y coordinate for point designated.
1	5	LREINP	New value of the longitudinal (axial) force in the reinforcement at the point designated.
1	6	TREINP	New value of the transverse (shear) force in the reinforcement at the point designated.

Repeat Line(s) 1 for additional points whose coordinates are to be changed in Modify Mode. More than one set of data (6 quantities) may be entered on a given line; however, each line of data must contain integer multiples of six quantities, comprising complete data sets. A blank line must be entered to terminate all Group J data and return to input of Command Words.

Group K - Data for the Analysis and Computations

79. The Group K input data designate whether circular or noncircular shear (potential sliding) surfaces are to be used to compute the factor of safety. The default procedure for calculating factor of safety is Spencer's (1967) procedure of slices as extended by Wright (1969, 1975); other procedures for computing the factor of safety may be selected as described later in this section. Regardless of the procedure used, the solution for the factor of safety involves subdividing the soil mass, which is bounded by the surface of the slope and an assumed shear surface, into a finite number of vertical slices and using an iterative procedure to compute the factor of safety. A number of trial shear surfaces must be tried to locate the surface which produces the minimum factor of safety.

80. The Group K input data also include data which determine the manner in which the soil mass is subdivided into vertical slices, the procedure used to compute the factor of safety, and several parameters which affect and/or control the iterative solution for the factor of safety. The Group K data also are used to designate if two-stage or three-stage stability computations are to be performed. All of the Group K data are described in this section.

81. UTEXAS3 allows the user either to specify individually selected shear surfaces, and the factor of safety is computed for each, or to designate that an automatic search is to be performed to locate a most critical shear surface having a minimum factor of safety. Shear surfaces may be either circular or noncircular. Individually specified shear surfaces are described below, first, followed by a description of the automatic searches.

82. The procedure used to compute the factor of safety and several variables which the user may optionally select are described following the description of the shear surfaces and automatic search. In the last part of this section, the format for the input data is described and presented.

Individually Specified Shear Surfaces

83. Individually selected shear surfaces may be either circular or noncircular. A combination of separate circular and noncircular shear surfaces may be selected and used to compute the factor of safety for a given problem. The shear surfaces may face to either the left or right of the slope, so that both faces may be analyzed for a given set of slope coordinate geometry. The

data for circular shear surfaces are somewhat different from the data for non-circular shear surfaces. Thus, the two shapes of shear surfaces are treated and described separately below.

Circular

84. The location of a given circular shear surface is defined in terms of the coordinates of the center of the circle and the radius of the circle. The x and y coordinates of the center of the circle are specified as input data. The radius either may be specified directly as input data or may be specified indirectly and calculated by the computer program using either of two indirect means. The two indirect means consist of specifying (with the input data for the circle) either the coordinates of a point through which the circle is tangent.

85. Subdivision into Slices. The soil mass bounded by the circular shear surface and the surface of the slope is subdivided into vertical slices automatically by the computer program. The subdivision into slices is performed using either one or the following two means, which may be selected by the user:

a. The mass is subdivided so that the angle which is subtended by the two radii extended to each side of the base of the slice (shear surface) does not exceed a certain, given value, "SUBDEG." In most cases many of the slices which are actually created will have a base which subtends an angle of less than the prescribed angle (SUBDEG) because of other constraints. For example, when the bottom of a slice would otherwise cross a boundary between two materials, a smaller slice width is used to ensure that the base of the slice lies in no more than one material.

b. The mass is subdivided so that the arc length along the base of each slice does not exceed a certain, given value, "ARCMAX." As in the first case, the actual arc length will be less than the value of ARCMAX for slices where other constraints dictate a narrower slice.

Initially the first option (1) above is selected and used as a default by UTEXAS3. That is, slices are created using a constant subtended angle; a value of 3 degrees is used for the angle. If the user desires, another value for the subtended angle or the alternate option, using a constant arc length (ARCMAX), may be selected. If either of the selected options and corresponding values of the parameters SUBDEG and ARCMAX results in more slices than the program can accommodate (due to the dimensioned size of arrays), the values of the angle or arc length will be successively doubled by the computer program until a small enough number of slices results.

86. Vertical "Tension" Crack. A vertical "tension" crack of selected depth, "DCRACK," may be specified for each individually selected circular shear surface with the Group K input data for the surface. The vertical crack is considered by the computer program to be located at the point where the shear surface reaches a depth equal to the specified depth (DCRACK) below the surface of the slope near the upslope portion of the shear surface. Thus, the lateral position of the crack is determined indirectly based on the location of the circle, the specified crack depth, and the slope geometry. The upslope end of the shear surface is determined by the program by comparing the elevation of the two ends of the shear surface; the highest end (excluding the presence of a crack) is determined to be the upslope end. In the case of a horizontal ground surface, the right end of the shear surface is assumed to be the upslope end of the shear surface, i.e., a horizontal ground surface is treated like a left-facing slope.

87. In addition to specifying a crack, the user may specify that the crack contains water or some other fluid. The presence of water in the crack is specified in the input data by specifying the depth of water, DWATER, in the crack. The user may also specify the unit weight of the water or other fluid in the crack, GAMAWC; otherwise, a unit weight of 62.4 is assumed (see Table 23 - Sub-Command Word "UNI"). The water specified in a crack is considered to produce a horizontal force in the crack equivalent to the force produced by hydrostatic pressures acting over the depth of water specified. However, such water is not considered to produce any pore water pressures in the soil or any other form of loading; pore water pressures and other loads must be specified separately by means of other input data (e.g., piezometric line, surface pressures, etc.).

Noncircular (Including Wedge)

88. The location of a noncircular shear surface is defined in the input data by specifying the x and y coordinates of selected points along the shear surface from left to right. The specified points are assumed to be connected by straight lines; vertical segments may not be specified. Specific shear surface coordinates required by the computer program, e.g., where the shear surface crosses a soil profile line, do not need to be included in the input data; the coordinates needed by the program will be computed and added to the coordinates input by the user.

89. In specifying the end points for a noncircular shear surface the user should be careful to specify the end point coordinates to be as precisely on the surface of the slope as is practically possible. However, if the specified end point coordinates do lie above (outside of) the slope, the computer program will attempt to adjust the coordinates so that they are located more precisely on the slope. This is done by determining the intersection of the specified shear surface with the surface of the slope and then changing the coordinates of the end point to those of the intersection point. However, the first two or last two end points on a shear surface must never both lie above the surface of the slope or an error condition with result. No adjustment is made to the end point coordinates for a noncircular shear surface when the point lies below the surface of the slope; in such instances a crack is assumed, as described later.

90. Subdivision into Slices. The soil mass above the noncircular shear surface is subdivided into a number of vertical slices by one of the following two means; which can be selected by the user as part of the input data:

a. The soil mass is subdivided so that the length of the base of each slice does not exceed a specified maximum value (BASEMX). To accomplish this the program first computes the coordinates which are required for other purposes, such as where the shear surface crosses a boundary between materials, and adds these required coordinates to the coordinates which were input. The program then checks the distance between each pair of adjacent points. If the distance exceeds the prescribed distance (BASEMX), the distance between the pair of points where the distance is exceeded is divided into a sufficient number of equal length increments to meet the required maximum slice base length.

b. The soil mass is subdivided to produce an approximate minimum number of slices, BASINC. The procedure used by the program takes the horizontal distance between the first and last point specified for the shear surface in the input data, divides the distance by the "minimum number of slices", BASINC, and then applies the computed distance as a maximum slice base length (equivalent to BASEMX) in the same manner as described for the first option above.

Initially the second option (Option 2) above is selected and used as a default by the computer program. That is, slices are created using a minimum number of slices, "BASINC", thirty (30) is used as the minimum number of slices. If the user desires, either another minimum number of slices or a "maximum slice base length", BASEMX, may be designated by input data. If either of the selected options and corresponding values of the parameters BASEMX and BASINC

results in more slices than the program can accommodate (due to the dimensioned size of arrays) the "maximum number of slices" will be reduced or "maximum base length" will be increased until a small enough number of slices results.

91. Vertical "Tension" Crack. A vertical "tension" crack, similar to what was described for a circular shear surface above, can be introduced for noncircular shear surfaces; however, the manner in which the crack is designated in the input data is different for noncircular shear surfaces. In the case of a circular shear surface the crack depth (DCRACK) is specified as a quantity in the input data. In the case of a noncircular shear surface the crack depth is not specifically input. Instead, the coordinates of the noncircular shear surface should be terminated on the right (in the case of a left facing slope) or initiated on the left (in the case of a right facing slope) at a point a depth below the surface of the slope equal to the desired depth of the "crack." A vertical crack is then assumed to extend from the last (or first) coordinate point specified to the top of the slope.

Automatic Searches

92. Automatic searches may be performed using either circular or noncircular shear surfaces. The automatic search procedures used in the computer program are designed to aid the user in locating the most critical shear surface corresponding to a minimum factor of safety. However, considerable judgment must be exercised in using the automatic search procedures to ensure that the most critical shear surface has actually been located. Careful judgment is especially important when more than one "local" minima exist. The search procedures used are very different, depending on whether the shear surface is circular or noncircular, and, thus, the procedures are described separately below.

Circular Shear Surfaces

93. During an automatic search the program uses one or more of the following three modes to locate the center of a critical circle:

a. Mode 1 - All circles pass through a given point, whose coordinates are specified.

b. Mode 2 - All circles are tangent to a given horizontal line, whose elevation (y coordinate) has been specified.

c. Mode 3 - All circles have a given radius, which is specified as part of the input data.

By successively varying the three available modes of search, according to the sequence of steps outlined below, the program is capable of locating an overall "critical" circle corresponding to a minimum value for the factor of safety.

a. Step 1: The critical circle is located for an initial mode of search which is specified as input data. The initial mode of search may be either Mode 1, 2 or 3 although Modes 1 and 2 are generally recommended for the initial mode. If Mode 1 is selected, the x and y coordinates of the point through which the circles pass are specified. If Mode 2 is selected, the y coordinate elevation of the horizontal tangent line must be specified. If Mode 3 is selected, the radius must be specified.

b. Step 2: Once a critical circle has been located for the initial mode of search, the mode of search is changed. If the initial mode of search was Mode 1 or Mode 3, the mode of search is changed to Mode 2, and a horizontal tangent line is defined at the elevation of the bottom of the critical circle which was located using the previous mode (Modes 1 or 3). If Mode 2 is specified for the initial search, the mode is changed to Mode 3, and the radius of the critical circle found in Mode 2 is adopted for subsequent use. If the difference between the values of the factor of safety for the two critical circles, located using the modes of Step 1 and Step 2, is less than 0.001, the critical circle is considered to be the most critical circle located in Step 2, and the search is completed. However, if the criterion is not satisfied, the search will continue to Step 3.

c. Step 3: After Step 2, the mode of search will be alternated between Modes 2 and 3, until the difference between the values of the minimum factors of safety for the critical circles found in successive modes is less than 0.001. Mode 1 will never be used beyond Step 1 and, thus, may only be used for the initial mode of search.

The program includes the option of terminating the search after Step 1 is completed (see Table 23 - Sub-Command Word "STO").

94. When locating the overall critical circle it may be desirable to impose a limiting depth below which the critical circle cannot pass. This may be achieved either by specifying a stratum of soil at the selected limiting depth and assigning a high shear strength to the particular stratum or by specifying an appropriate limiting elevation below which the critical circle is not allowed to pass. The selected limiting y elevation is specified in the data input for the search as the variable YLIMIT.

95. For each mode of search the location of the center of the critical circle is found by using a 3 by 3, 9-point, square grid. The center point of the first grid used for the initial mode of search is specified in the input data and should represent a best estimate of the x and y coordinates of the center of the critical circle. The initial spacing between points in the 9-point grid is thirty (30) times a specified distance, ACCURC. The distance (ACCURC) is entered as input data and may be considered to be the approximate accuracy with which the center of the critical circle is to be eventually determined.

96. The location of the center point of the grid is shifted during the search until the center of the grid corresponds to the center of a circle which has a lower value for the factor of safety than any of the eight other circles whose centers are located on the perimeter of the grid. The 9-point grid is always shifted such that the center of the new grid is located at the point where the lowest value of the factor of safety was determined using the previous grid. The spacing between grid points is also changed during the automatic search. The spacing is reduced from the initial spacing which is 30 times the specified distance, ACCURC, to spacings of 5, 3 and, finally, 1 times the distance, ACCURC. Computed values for the factor of safety are stored by the program, and in most cases values are calculated for only those circles where values have not been previously computed. The search in a given mode is terminated and the next mode or other appropriate action is taken when the grid spacing has been reduced to the specified distance (ACCURC) and the center of the 9-point grid corresponds to the lowest factor of safety.

97. Experience with the "gridded" search procedure has shown that specified distances, ACCURC, ranging from one percent to ten percent of the slope height work well for locating the critical circle. However, the actual distances used should be selected based on each individual problem to ensure that a critical circle is found. In any case the distance should not exceed the thickness or smallest dimension of the smallest zone of soil which may influence the computed minimum factor of safety and critical shear surface.

98. During an automatic search the program does not permit the search to "jump" from one face of the slope to another. For example, if the initial trial shear surface is for the left face of the slope, shear surfaces on the right face of the slope will be rejected and not considered.

99. In some cases it will be possible to find several local "critical" circles with minimum factors of safety. The center of each such locally critical circle will be surrounded by center points having higher values for the factor of safety. In such cases, when a given search is performed, only one of the locally critical circles will be searched-out and located; the circle so found may not be the one with the absolute, lowest value for the factor of safety. In order to locate the circle with the absolute, lowest value for the factor of safety, several automatic searches will need to be performed using different starting points for the circles and, perhaps, different initial modes for the search. The values of the factor of safety for each of the "critical" circles located by these independently started searches must then be compared by the user to determine the actual value of the minimum factor of safety and the location of the overall critical circle. This will require that several sets of Group K data be specified for a given problem.

100. When the search option is used, the procedure for subdividing the circle into slices is identical to the procedure described previously for individual circular shear surfaces. Similarly, a vertical "tension" crack depth may be specified and the crack may be designated to contain water or some other fluid, as described earlier for individually specified circular shear surfaces.

Noncircular Shear Surfaces (Including Wedge)

101. An automatic search for a critical noncircular shear surface is performed using a procedure very similar to the procedure developed by Celestino and Duncan (1981). In this procedure the shear surface is systematically moved from an initial (starting) position, which is assumed by the user, until a minimum factor of safety is calculated. The initial position of the shear surface is specified by the user and should correspond to the best estimate for the location of a critical shear surface. If the slope contains a thin seam of relatively weak material, through which the critical shear surface is expected to pass, the initial shear surface should be input so that it passes through the weaker material. The location of the initial shear surface is specified in the input data by a series of coordinates along the shear surface (from left to right), much as an individual shear surface is specified when no search is to be performed.

102. At the user's option, the coordinate points which are input to define the initial shear surface either may be allowed to move during the search or may be considered fixed; however, in most cases all points would be considered to be moveable. As the first step in an automatic search, each moveable point on the shear surface is moved an incremental distance (specified by the input data) in each of two opposite directions (e.g., up and down). Points are moved one by one on A TEMPORARY basis and a factor of safety is calculated for the shear surface with each point at each of the two positions to which it is moved. Figure 7 illustrates the temporary movement of the points. When any one point is moved, all other points are left at their original (initial) positions; no points are permanently shifted during the first step of the automatic search. The direction in which points are moved may be specified by the user as input data for each point, or UTEXAS3 will automatically compute a direction for shifting each point. When UTEXAS3 computes a direction for shifting each point, the direction is taken as approximately normal (perpendicular) to the shear surface; the direction may, thus, change somewhat as the shear surface moves. End points on the shear surface are moved along the slope, or parallel to the slope, in the case of a vertical "tension" crack. Thus, the user has no control over the direction of movement of the two end points of the shear surface.

103. Once each point on the shear surface has been shifted and the factor of safety has been computed for each shift, a new estimate for the position of the most critical shear surface is made and the initial shear surface is PERMANENTLY moved. The new estimate for the position of the shear surface is made using the procedure of Celestino and Duncan (1981); the factor of safety is assumed to vary parabolically with the position of the shear surface.

104. Once the new estimate of position for the shear surface is made and the surface is moved, each point is again shifted in the manner used for the first step and the process is repeated to find yet another estimate for the critical shear surface.

105. The distance each point is temporarily shifted to compute the factor of safety is determined based on an "initial incremental shift distance" (DSHIFT), which is specified by input data. Initially the points will be shifted a distance equal to the specified distance, DSHIFT. The distance

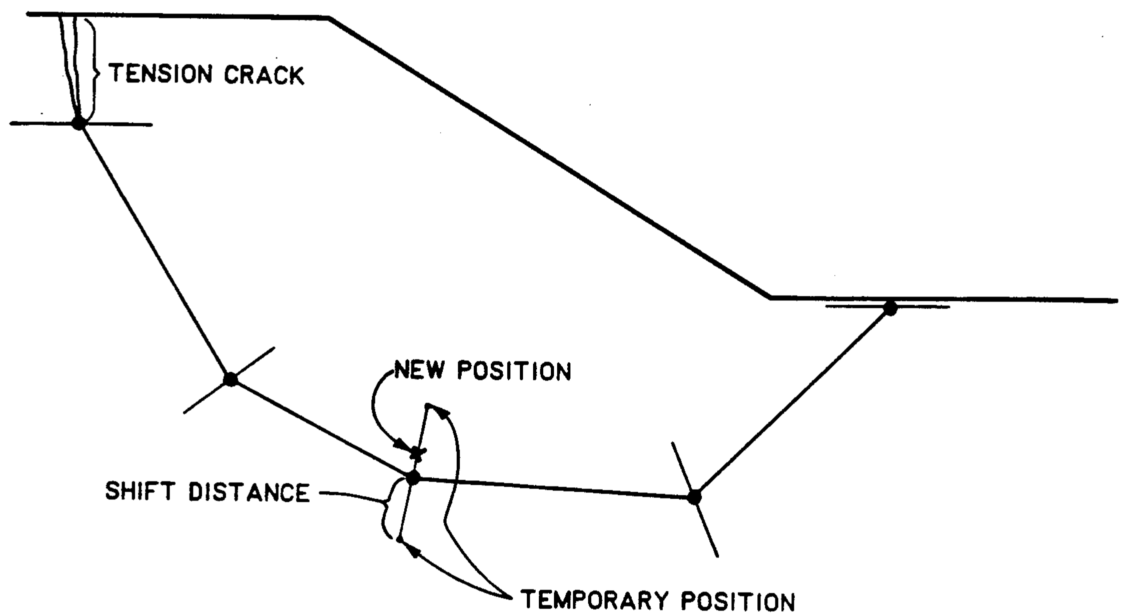


Figure 7. Temporary movement of the points

shifted will later be reduced automatically by the computer program as the distance which the shear surface is permanently moved (as opposed to temporarily shifted) on each "step" or "trial" diminishes. (The actual distance the shear surface is permanently moved on each step is computed by UTEXAS3.) The distance the shear surface is temporarily shifted is reduced from the initial value to 70 percent, 40 percent, and finally, 10 percent of the initial value. Thus, the "precision" in the final location of the shear surface will be approximately 10 percent of the specified initial distance, DSHIFT.

106. In most procedures of limit equilibrium slope analysis the equilibrium equations used to compute the factor of safety will begin to yield unrealistic values for the stresses near the toe of shear surfaces which are inclined upward at angles much steeper than those which would be logically based on considerations of passive earth pressure. Trial shear surfaces can potentially become excessively steep in an automatic search unless some restriction is placed on the amount the shear surface is shifted during the trial-and-error search. Accordingly, in addition to specifying the distance DSHIFT used by the automatic search, the user may specify a maximum steepness to be allowed for the "toe" portion of the shear surface. The "toe" portion is considered to be any portion of the shear surface which is inclined upward

in a direction opposite to the slope face. The maximum steepness allowed is specified by a value for the optional parameter ALFMAX in the input data for the noncircular shear surface. (A default value of 50 degrees is assumed if no value is input.)

107. Judgment and some trial and error may be required in selecting an optimum value for the incremental shift distance, DSHIFT. Experience to date indicates that relatively large distances may be used provided that the limiting steepness (ALFMAX) described above is not specified to be in excess of 50 degrees (the default value). As described above, the final distance used to shift the shear surface will be equal to 10 percent of the initial distance, DSHIFT. Thus, the initial distance should be selected such that the final distance will result in an acceptably refined location for the most critical shear surface. In general it is anticipated that the location of the final shear surface will be determined to within no more than 10 to 25 percent of the thickness of the thinnest stratum through which the shear surface may pass. For example, if a stratum is 5 feet thick and an acceptable degree of resolution for the critical shear surface is selected to be 20 percent of the thickness of a stratum, the initial shift distance, DSHIFT, would be 10 feet (= 20 percent of 5 feet divided by 10 percent, where 10 percent represents the final fractional amount of DSHIFT used for the search).

108. A vertical crack, similar to the ones described previously, may be used in an automatic search with noncircular shear surfaces. The crack is designated in essentially the same way as described for individually specified noncircular shear surfaces by terminating (or starting) the end point coordinates of the initial shear surface at some depth below the surface of the slope. The crack depth determined for the initial trial shear surface is assumed to apply to all of the noncircular shear surfaces attempted during a search. The crack depth (DCRACK), which can be input as a separate quantity in the input data for circular shear surfaces, has no significance in the input data for noncircular shear surfaces.

Seismic Coefficient

109. The computer program permits the user to perform "pseudo-static" analyses in which a horizontal body force is applied to each slice to simulate earthquake loading. This is accomplished using a single seismic coefficient (SEISCF) by which the weight of each slice is multiplied to obtain the

horizontal body force. The body force is assumed to act through the approximate center of gravity for each slice. A positive seismic coefficient corresponds to a force acting to the left for the left face of a slope and to the right for the right face of a slope. The seismic coefficient is specified as part of the Group K data (see Table 23 - Sub-Command Word "SEI"). UTEXAS3 assumes that there are no seismic forces (default) unless a seismic coefficient is input; however, once a value is input it remains in effect either until another value, including zero, is input with Group K data or asterisks ("***") are encountered in the Command Words. No special treatment is given to shear strengths when a seismic coefficient is used; the shear strengths are defined and interpreted in the normal manner as described in paragraphs 35 through 44. The only effect which a seismic coefficient has on the computations is to pro-duce an added, horizontal body force on each slice. Generally, analyses with a seismic coefficient should be performed using two-stage computations. The strength used for the second stage should reflect any loss in strength due to earthquake shaking.

Computation for Factor of Safety

110. The procedure used to compute the factor of safety may be selected by the user although Spencer's procedure is strongly recommended. The procedures available to the user are briefly described below followed by a discussion of input parameters.

Procedures for Computing F

111. Four procedures are available for computing the factor of safety. The procedures are (1) Spencer's procedure, (2) the Simplified Bishop procedure, (3) the Corps of Engineers' Modified Swedish procedure, and (4) Lowe and Karafiath's procedure. The Simplified Bishop procedure is restricted to computations with circular shear surfaces while the other procedures may all be used with either circular or noncircular shear surfaces. Attempts to use the Simplified Bishop procedure for noncircular shear surfaces will result in an error condition and computations will not be attempted by the program.

112. Spencer's Procedure. In Spencer's procedure all side forces are assumed to have the same inclination and all requirements for static equilibrium are satisfied. The trial and error solution involves successive

assumptions for the factor of safety and side force inclination until both force and moment equilibrium are satisfied.

113. Simplified Bishop Procedure. The side forces are assumed to act horizontally in the Simplified Bishop procedure. Thus, there are no shear forces on the vertical boundaries between slices. Equilibrium of forces in the vertical direction is satisfied for each slice and equilibrium of moments about the center point of the circular shear surface is satisfied for the entire soil mass consisting of all slices. The trial and error solution for the factor of safety involves successive assumptions for the factor of safety until the moment equilibrium equation is satisfied (force equilibrium is implicitly satisfied).

114. Corps of Engineers' Modified Swedish Procedure. In the Modified Swedish Procedure all side forces are assumed to have the same inclination (are parallel) and the inclination is assumed by the user. According to US Army Corps of Engineers (1970) the inclination is assumed to be equal to the "average slope of the embankment," however, other, often flatter, inclinations are frequently assumed in practice. The Modified Swedish procedure satisfies equilibrium of forces in both the vertical and horizontal directions for individual slices, but does not satisfy moment equilibrium. The procedure has been found to sometimes overestimate the factor of safety by as much as 50 percent or more and the results are sometimes very sensitive to the assumed inclination for the side forces. The trial and error solution for the factor of safety involves successive assumptions for the factor of safety until the equilibrium of forces is satisfied.

115. Lowe and Karafiath's Procedure. Lowe and Karafiath's procedure is identical to the Corps of Engineers' Modified Swedish Procedure except for the assumed inclinations of the side forces. In Lowe and Karafiath's procedure the side forces are assumed to be inclined at the average slope of the ground (slope) surface directly above and the shear surface directly below each vertical slice boundary as shown in Figure 8. Thus, the side force inclinations generally vary from slice-to-slice. (In UTEXAS3 side force inclinations are computed by averaging "slopes," dy/dx, rather than angles.) The trial and

error solution for the factor of safety in Lowe and Karafiath's procedure is identical to the one for the Modified Swedish procedure.

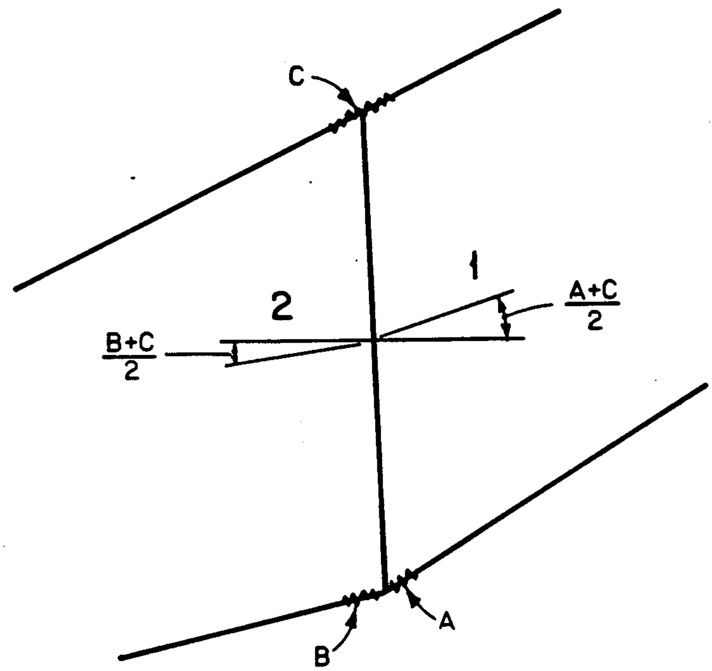


Figure 8. Side-force inclination for Lowe and Karafiath's procedure

<u>Solution Parameters</u>

116. All of the procedures for computing the factor of safety involve an iterative solution in which successive values are assumed for the factor of safety, and side force inclination in the case of Spencer's procedure, until one or more equilibrium equations are satisfied. The iterative solutions involve a number of "solution" parameters. The computer program assumes default values for the "solution" parameters with one exception—the side force inclination used in the Corps of Engineers' Modified Swedish procedure must be selected and input by the user; a default value is not assumed. Experience to date (1990) indicates that the default values assumed in the computer program have been adequate for most of the problems which have been worked; however, needs may arise to change some of the values from those assumed by the program. The most important parameters used in the solutions are described and discussed in further detail below.

117. The iterative solution for the factor of safety is initiated with initial trial values for the factor of safety, "FZERO" (and side force inclination, "TZERO," in the case of Spencer's procedure). The trial values are then changed by successive approximations until all of the following conditions are satisfied, i.e., the solution converges:

a. Static equilibrium is satisfied within acceptable limits of accuracy. These limits are defined in terms of "allowed" imbalances, "FIMBAL," in the case of forces, and "MIMBAL," in the case of moments. The specific imbalance limits which are satisfied depend on the procedure being used to compute the factor of safety (Spencer, Simplified Bishop, etc.).

b. The value of the factor of safety changes by no more than 0.00001 on successive iterations. In the case of Spencer's procedure the side force inclination must also not change by more than 0.0001 radians on successive iterations.

If either of the above two conditions for convergence is not satisfied within a certain maximum number of iterations (MXITER), computations for the particular shear surface will be abandoned and the next shear surface will be considered.

118. The initial trial values (FZERO and TZERO), the force and moment imbalances (FIMBAL and MIMBAL), and the allowable number of iterations (MXITER) are all assigned default values by the computer program. The default values are given in Table 13.3 and any one or all of the values may be changed by the user through selective input of data. Several important features of the iterative solution for the factor of safety and side force inclination as well as the variables FZERO, TZERO, FIMBAL, MIMBAL, and MXITER are described below.

119. Factor of Safety. The value of the factor of safety is permitted to change only by a maximum of five-tenths (0.5) on successive iterations. This constraint is placed on the solution to ensure proper convergence. However, if a very inaccurate estimate is made and specified for the initial value of the factor of safety (FZERO), the correct value may not be reached within the prescribed maximum number of iterations and the solution will fail to converge. Similar problems with convergence may develop when an automatic search is being performed and a trial shear surface passes through a zone of very high shear strength, such as concrete or a firm (rock) stratum, which has been specified for the purpose of limiting the extent of the critical shear surface. In this case a relatively large value for the factor of safety will

be sought, but probably the value will not be reached by the program within the allowed number of iterations. Thus, an indication will be given on the printed output that the solution did not converge. In this case the problem of a solution not converging for one of the trial shear surfaces attempted during an automatic search is normally of no practical consequence, and the user should verify that, for the shear surfaces where the solution did not converge, the values for the factor are relatively large.

120. In addition to the constraint described above for the change in the factor of safety on successive iterations (0.5), the value of the factor of safety is not permitted to become less than one-tenth (0.10). While this constraint should be of little practical consequence, the solution will be terminated when the value for the factor of safety reaches a value of one-tenth.

121. A considerable amount of experience has shown that the numerical solution for the factor of safety and side force inclination is better conditioned and more likely to converge when the initial trial value for the factor of safety overestimates, rather than underestimates, the correct value. In many cases by simply increasing the initial estimate for the factor of safety (FZERO) the solution can be made to converge, where otherwise convergence was not achieved.

122. Side Force Inclination (Spencer's Procedure). In Spencer's procedure the inclination of the resultant forces between the vertical slices is assumed to be the same for all slices and is calculated along with the factor of safety as part of the iterative solution. The angle of inclination of the side forces is measured from the horizontal plane and positive values are measured in a counter-clockwise direction. The side force inclination will normally be positive for a left facing slope and negative for right facing slope.

123. In the iterative solution procedure, the value of the side force inclination is not permitted to change by more than 0.15 radians (approximately 8.6 degrees) on successive iterations and will be adjusted accordingly by the program when this limit is reached. In addition, the side force is not permitted to reach an inclination steeper than either +80 degrees for a left facing slope or -80 degrees for a right facing slope. If these limits are reached, the iterative solution will be terminated with an appropriate message. Also, a side force inclination of less than -10 degrees for a left

facing slope or greater than +10 for a right facing slope will cause the solution to be terminated with an appropriate message.

124. Side Force Inclination (Modified Swedish Procedure). In the Corps of Engineers' Modified Swedish procedure the inclination of the side forces is assumed by the user. The value which is input to UTEXAS3 is interpreted to be the absolute value of the inclination, measured in degrees from the horizontal plane. The computer program will then assign an appropriate sign to the inclination angle which is input depending on the inclination of the slope face being considered by a particular shear surface. Positive values are measured in a counter-clockwise direction. The program assigns a positive value for a left-facing or horizontal slope and a negative value for a right-facing slope.

125. Allowed Force and Moment Imbalance. The allowed force and moment imbalances are used as one of the criteria for convergence as noted earlier. Depending on the specific procedure being used to compute the factor of safety the solution will satisfy, within the specified imbalances, force equilibrium (Modified Swedish procedure, Lowe and Karafiath procedure), moment equilibrium (Simplified Bishop), or both force and moment equilibrium (Spencer's procedure). The Simplified Bishop procedure also satisfies force equilibrium in the vertical direction; however, it satisfies force equilibrium exactly and, thus, the imbalance is zero.

126. The default values assumed by the computer program for force and moment equilibrium are 100 pounds and 100 foot-pounds, respectively. Experience with the computer program to date (1990) has shown that for most typical slopes analyzed, the value of the factor of safety is computed to within a minimum of four significant figures (0.01 percent) of the exact solution using the assumed, default values. (The values for the limits of force and moment imbalance may not be specified as zero, because roundoff error and use of a finite number of significant figures by the computer preclude computation of precisely zero values for verifying convergence.)

127. Iteration Limit. When reasonable values are assumed for the initial trial values of the factor of safety and side force inclination, convergence to a solution is normally attained within from three to ten iterations. This assumes that the factor of safety is estimated to within the correct value by approximately 1.5 and, in the case of Spencer's procedure, that the

side force inclination is estimated to within 20 degrees of the correct value. If the solution fails to converge within an apparently reasonable number of iterations, the user should examine the step-by-step output from the iterative solution to establish the reasons for non-convergence. For an automatic search, step-by-step output from the iterative solution is available only for the final, most critical surface. Accordingly, when severe non-convergence problems are encountered during an automatic search, the user should specify a single, individual shear surface and examine the step-by-step output from the iterative solution (see paragraphs 133 through 172 - Description of Tables 29, 34, and 37).

Special Note for Automatic Searches

128. During an automatic search some efficiency may be realized by changing the initial trial values used for the factor of safety (and side force inclination in the case of Spencer's procedure), from the values used at the start of the search. Improved estimates for the trial values can be obtained by using the values corresponding to the lowest factor of safety computed at any stage during the search. Such improved estimates can be used by activating an option in the computer program whereby the initial trial values will be set to those corresponding to the lowest factor of safety (see Table 23 - Sub-Command Word "CHA"). Activation of this option may improve the efficiency of the calculations during a search, but can also cause problems with convergence of the numerical solution to correct values. The option should be used with caution, especially when an automatic search is being performed using noncircular shear surfaces.

Special Note for Nonlinear Strength Envelope

129. When the Mohr-Coulomb shear strength envelope is nonlinear, the calculations for the factor of safety are repeated several times for each trial shear surface. Shear strengths are first estimated for each slice where a nonlinear envelope applies and a factor of safety is calculated. This permits the normal stresses on the shear surface to then be calculated (the normal stresses depend on the shear strength and the factor of safety) and new shear strengths are calculated. This process is repeated until a consistent set of values of shear strength and normal stress are found for each slice.

Form for Data Input

130. The Group K data are used to designate whether circular or noncircular shear (sliding) surfaces are to be used to compute the factor of safety and whether a single, individually specified shear surface is to be considered or an automatic search is to be performed to locate a most critical shear surface with a minimum factor of safety. Depending on the options selected (circular versus noncircular; search versus individual shear surface), certain additional information is required. For example, for a single circular shear surface, the coordinates of the center of the circle and the radius might be input.

131. In addition to the required data in Group K there are numerous quantities and options for which the computer program assumes default values, but which the user may change. Once the required data have been input, users can designate by optional "Sub-Command" words, which of the quantities and options they wish to change from the default values. One of the optional quantities is the depth of vertical crack (DCRACK); often a value other than the default value of zero is assigned. Once any optional quantity has been defined by Group K input data it remains as it has been defined until new Group K data specifically redefine or reset the optional quantity. Thus, new Group K data may be input, but if they do not specifically redefine the optional quantity from the value set by previous Group K data, the optional quantity remains as it was previously set. Thus, for example, once a crack depth is entered it remains in effect until redefined.

132. The Group K data must immediately follow the Command Word "ANA" (or "ANALYSIS/COMPUTATION"). The form for the required data, which must be input first, is presented in Table 18 and Tables 19 through 22. The form for the optional Sub-Command Words and data which may follow the required data is presented in Table 23.

Table 18

Group K - Analysis and Computation Data Input

Format - Required Input Line No. 1

Input Line No.	Data Field No.	Variable/Description	
1	1	CHAR(1)	A single character or a single, continuous character string beginning with one of the appropriate characters to indicate the shape of the shear surface as follows: "C" (or "CIRCULAR") to designate that circular shear surfaces are to be used to compute the factor of safety. "N" (or "NONCIRCULAR") to designate that noncircular shear surfaces are to be used to compute the factor of safety.
1	2	CHAR(2)	Either (1) a single character or (2) a single, continuous character string beginning with the appropriate character or (3) blank to indicate whether a single shear surface or an automatic search is to be used for the analysis as follows: "S" (or SEARCH) to designate that an automatic search is to be performed to find a shear surface with a minimum factor or safety. " " (= blank) to designate that only a single shear surface is to be considered. Note: Additional single shear surfaces may be input by additional sets of Group K -Analysis/ Computation data.

Note: Only enter character - omit quotes (").

Depending on the characters input on Line 1, proceed as follows:

Characters Input	Interpretation - Required Additional Input
"C" " " (=blank)	Single circular shear surface; input lines 2A, 3A, 4A, 5A and 6A as required - See Table 19.
"N" " " (=blank)	Single noncircular shear surface; input lines 2B and 3B - See Table 20.
"C" "S"	Search with circular shear surfaces; input lines 2G, 3C, 4C and 5C as required - See Table 21.
"N" "S"	Search with noncircular shear surfaces; input lines 2D, 3D and 4D - See Table 22.

Table 19

Group K - Analysis and Computation Data Input Format - Single Circular Shear Surface, Required Input Line Nos. 2A through 6A

Input Line No.	Data Field No.	Variable	Description
2A	1	XCENTR	X coordinate for center of circle.
2A	2	YCENTR	Y coordinate for center of circle.
2A	3	RADIUS	Radius of circle. Note: The radius can be left blank and will then be computed by the program using data input on lines 3A through 5A. If radius is blank, proceed with line 3A. If not blank, skip lines 3A through 5A and proceed to line 6A.
3A	1	CHAR(1)	A single character or character string beginning with the appropriate character to indicate how the radius is to be defined as follows: "P" (or "POINT") to designate that the circle passes through a fixed point; proceed to Line 4A. "T" (or "TANGENT") to designate that the circle is to be tangent to a specified horizontal line; proceed to Line 5A.
		Note: Only enter character - omit quotes (").	
4A	1	XFIXED	X coordinate value of point through which circle passes.
4A	2	YFIXED	Y coordinate value of point through which circle passes.
		After this line (4A) proceed to Line 6A below.	
5A	1	YTANLN	Y coordinate of horizontal line to which circle is tangent.
		After this line (5A) proceed to Line 6A below.	
6A	1	Use a blank line to terminate all Group K date and then proceed with Command Words (paragraphs 22 through 25) when none of the Optional quantities is to be defined or reset. If the Optional quantities are to be input, omit this blank line (6A) and proceed directly with the Sub-Command Words in Table 23.	

Table 20

Group K - Analysis and Computation Data Input Format - Single Noncircular Shear Surface, Required Input Line Nos. 2B and 3B

Input Line No.	Data Field No.	Variable/Description	
2B	1	X	X coordinate of point used to define the non-circular shear surface.
2B	2	Y	Y coordinate of point used to define the noncircular shear surface.
		Repeat Line(s) 2B for additional points, from left to right, to define the noncircular shear surface. Input a blank line to terminate the data for the shear surface.	
3B	1	When none of the optional quantities in the Group K data is to be defined or reset, input a blank line here as Line 3B to terminate all Group K data, and then proceed with the Command Words as described in paragraphs 22 through 26. (Note: In this case the Group K data will actually end in two blank lines - one line 2B and one Line 3B.) If optional quantities in Group K are to be input, omit this blank line (3B) and proceed directly with the Sub-Command Words as described in Table 23.	

Table 21

Group K - Analysis and Computation Data Input Format - Automatic Search with Circular Shear Surfaces, Required Input Line Nos. 2C through 5C.

Input Line No.	Data Field No.	Variable	Description
2C	1	XSTART	Starting X coordinate for center of circle used in search.
2C	2	YSTART	Starting Y coordinate for center of circle used in search.
2C	3	ACCURC	Accuracy for finding center of critical circle (= minimum grid spacing).
2C	4	YLIMIT	Y coordinate for limiting depth to which critical circle will be allowed to pass.
3C	1	CHAR(1)	Single character or continuous character string beginning with appropriate character to indicate what initial mode of search will be used as follows: "P" (or "POINT") - Circles all pass through a common fixed point: proceed next to Line 4C-1. "T" (or "TANGENT") - Circles all tangent to specified horizontal line; proceed to Line 4C-2. "R" (or "RADIUS") - Circles all have the same radius; proceed next to Line 4C-3.
		Note:	Only enter character - omit quotes (").
4C-1	1	XFIXED	X coordinate value of fixed point.
4C-1	2	YFIXED	Y coordinate value of fixed point.
		After Line 4C-1, proceed directly to Line 5C.	
4C-2	1	YTANLN	Y coordinate of horizontal line to which all circles are tangent.
		After Line 4C-2 proceed directly to Line 5C.	
4C-3	1	RADIUS	Constant radius to be used in the initial mode of search.
		After Line 4C-3, proceed with Line 5C.	

(Continued)

Table 21 (Concluded)

Input Line No.	Data Field No.	Variable/Description
5C	1	When none of the optional quantities in the Group K data is to be defined or reset, input a blank line here as Line 5C to terminate all Group K data, and then proceed with the Command Words as described in paragraphs 22 through 26 (Tables 1 and 2). If optional quantities in Group K are to be input, omit this blank line (5C) and proceed directly with the Sub-Command Words as described in Table 23.

Table 22

Group K - Analysis and Computation Data Input Format - Automatic Search with Noncircular Shear Surfaces, Required Input Line Nos. 2D through 4D

Input Line No.	Data Field No.	Variable/Description	
2D	1	X	X coordinate of point used to define the initial, trial noncircular shear surface for the automatic search.
2D	2	Y	Y coordinate of point used to define the initial, trial noncircular shear surface for the automatic search.
2D	3	Information to designate if and how this point is to be shifted, as follows:	
			- If blank, the point is considered to be moveable and it is moved in a direction approximately perpendicular to the shear surface at that point.
			- If a numerical value (non-blank) is input, the point is considered to be moveable and the numerical value, which was input, is interpreted to define the direction in which the point is to be moved. The numerical value, i.e., the direction, should be an angle measured in degrees from the horizontal and being positive in the counter clockwise direction.
			- If the characters, "FIX", are input in Field No. 3 then the point is assumed to be fixed and is not moved during the automatic search.
		Repeat Line(s) 2D for additional points, from left to right, to define the initial, trial noncircular shear surface. Input a blank line of data (Line 2D) to terminate the coordinates for the initial trial noncircular shear surface and then proceed with Line 3D.	
3D	1	DSHIFT	Initial distance for shifting points on the noncircular shear surface in the automatic search. The final distance used to shift points ("accuracy") will be 10 percent of this distance.

(Continued)

Table 22 (Concluded)

Input Line No.	Data Field No.	Variable/Description
3D	2	ALFMAX Maximum steepness permitted for shear surface near toe portion of the slope. Expressed as an angle measured in degrees from the horizontal plane. This second variable on Line No. 3D is optional; the program will assume a default value of 50 degrees if none is input.
4D	1	When none of the optional quantities in the Group K data is to be defined or reset, input a blank line here as Line 4D to terminate all Group K data, and then proceed with the Command Words as described in paragraphs 22 through 26. If optional quantities in Group K are to be input, omit this blank line (4D) and proceed directly with the Sub-Command Words as described in Table 23.

Table 23

Group K - Analysis and Computation Data Input Format - Optional Input following Required Input

Input Line No.	Data Field No.	Variable/Description
1	1	COMWRD Sub-Command Word consisting of a character string, the first three characters of which designate which optional quantity is to be defined or reset. The acceptable characters and the optional quantities which they designate are as follows:
		"TWO" (TWO-stage computations) - Designates that two-stage stability computations are to be performed. After this Sub-Command Word proceed directly with additional Sub-Command words, i.e., input another Line 1.
		"THR" (THRee-stage computations) - Designates that three-stage stability computations are to be performed. After this Sub-Command Word proceed directly with additional Sub-Command words, i.e., input another Line 1.
		"FAC" (FACtor of safety) - An initial trial value for the factor of safety will be input; proceed next to Line 2A.
		"SID" (SIDE force inclination) - An initial trial value for the side force inclination will be input; proceed next to Line 2B.
		"ITE" (ITEration limit) - An iteration limit will be input; proceed next to Line 2C.
		"FOR" (FORce imbalance) - A value for allowable force imbalance will be input; proceed next to Line 2D.
		"MOM" (MOMent imbalance) - A value for allowable moment imbalance will be input; proceed next to Line 2E.

(Continued)

Table 23 (Continued)

Input Line No.	Data Field No.	Variable/Description	
		"CHA"	(CHAnge initial trial factor of safety) - This designates that during an automatic search the initial trial value for the factor of safety will be automatically changed and assumed to be equal to the lowest value of the factor of safety computed at any point in the search. This can reduce the time required to compute the factor of safety, but can also lead to occasional convergence problems in the solution. If this option is not set the initial trial value remains as the default/input value - See "FAC" above. Proceed directly with additional Sub-Command Words (Line 1) after this "word." This Command Word acts as a "toggle" switch, turning the option on/off each time encountered.
		"OPP"	(OPPosite sign convention) - This designates that the opposite sign convention from the one assumed by the program based on a direction of potential sliding is to be used. See the special note for flat slopes in Section 9. Proceed directly with additional Sub-Command Words (Line 1) after this "word." This Command Word acts as a "toggle" switch, turning the option on/off each time encountered.
		"SHO"	(SHOrt-form output) - This designates that the short-form of output table, rather than the long form, is to be printed for an automatic search. This Command Word acts as a "toggle"switch, turning the option on/off each time encountered.
		"SUB"	(SUBtended angle) - A value of subtended angle for slice generation with a circular shear surface will be input; proceed next to line 2F.

(Continued)

Table 23 (Continued)

Input Line No.	Data Field No.	Variable/Description	
		"ARC"	(ARC length) - A value of maximum arc length for slice generation with a circular shear surface will be input; proceed next to Line 2G.
		"CRA"	(CRAck depth) - A crack depth is to be input; proceed next to Line 2H.
		"BAS"	(BASE length) - A value of maximum slice base length for slice generation with a noncircular shear surface is to be input; proceed next to Line 2I.
		"INC"	(INCrements for slice generation) - A value for the number of increments for slice generation with a noncircular shear surface is to be input; proceed next to Line 2J.
		"STO"	(STOP) - Designates that an automatic search with circular shear surfaces is to be terminated after the initial mode has been completed (See Line 3C - Table 21). After this Sub-Command word proceed directly with additional Sub-Command words, i.e., input another Line 1.
		"CRI"	(CRItical) - Designates that automatic search is to be continued (after the initial mode has been completed) to locate a most critical circle. This is the default unless set by "STO" above. After this Sub-Command Word proceed directly with additional Sub-Command words, i.e., input another Line 1.
		"WAT"	(WATer depth) - A depth of water in the vertical crack is to be input; proceed next to Line 2K.
		"UNI"	(UNIT weight of water) - A unit weight for water (or other fluid) in the vertical crack is to be input; proceed next to Line 2L.

(Continued)

Table 23 (Continued)

Input Line No.	Data Field No.	Variable/Description	
			"SEI" (SEIsmic Coefficient) - A value for the seismic coefficient will be input; proceed next to line 2M.
			"PRO" (PROcedure for computation of F) - The procedure to be used to compute the factor of safety is to be input; proceed next to Line No. 2N.
		Input a blank Sub-Command word to terminate all the Group K input data.	
2A	1	FZERO	Initial trial value of factor of safety used in iterative solution. A default value of 3.0 is used if none is input. After input return to Line 1.
2B	1	TZERO	Initial trial value of side force inclination used in iterative solution (in degrees). A default value of 15 degrees is used if none is specified. After input return to Line 1.
2C	1	MXITER	Maximum number of iterations to be permitted in iterative solution for factor of safety. A default value of 40 is used if none is input. After input return to Line 1.
2D	1	FIMBAL	Maximum force imbalance permitted for convergence of iterative solution for factor of safety. A default value of 100 is used if none is input. After input return to Line 1.
2E	1	MIMBAL	Maximum moment imbalance permitted for convergence of iterative solution for factor of safety. A default value of 100 is used if none is input. After input return to Line 1.
2F	1	SUBDEG	Subtended angle for slice generation (in degrees). A default value of 3 degrees is used if none is input. After input return to Line 1.
2G	1	ARCMAX	Maximum arc length for slice generation. See Line 2F for SUBDEG above regarding relevant default values. After input return to Line 1.
2H	1	DCRACK	Vertical ("tension") crack depth. A default value of zero (no crack) is used if none is input. After input return to Line 1.

(Continued)

Table 23 (Continued)

Input Line No.	Data Field No.	Variable/Description	
2I	1	BASEMX	Maximum slice base length for slice generation (noncircular shear surfaces only). See Line 2J for BASINC below regarding relevant default values. After input return to Line 1.
2J	1	BASINC	Number of increments into which shear surface is subdivided for slice generation (noncircular shear surfaces only). A default value of 30 is used if none is input. After input return to Line 1.
2K	1	DWATER	Depth of water or other fluid in vertical crack. A default value of zero (no water) is used if none is input. After input return to Line 1.
2L	1	GAMAWC	Unit weight of water (or other fluid) in vertical crack. A default value of 62.4 is used if none is input. After input return to Line 1.
2M	1	SEISCF	Seismic coefficient. No (zero) seismic coefficient is assumed initially. After input return to Line 1.
2N	1	METHOD	A single character or a character string beginning with the appropriate character to indicate the procedure for computing the factor of safety as follows: "S" (or "SPENCER") for Spencer's procedure. "B" (or "BISHOP") for the simplified Bishop procedure. "C" (or "CORPS") for the Corps of Engineers' Modified Swedish procedure. "L" (or "LOWE") for Lowe and Karafiath's procedure. Spencer's procedure is recommended and assumed as the default procedure. <u>NOTE</u>: If the Corps of Engineers' Modified Swedish procedure is selected proceed to Line No. 3 for the side force inclination. Otherwise return to Line No. 1 after this line of input.

(Continued)

Table 23 (Concluded)

Input Line No.	Data Field No.	Variable/Description	
3	1	CTHETA	Constant value of side force inclination to be used in the Corps of Engineers' Modified Swedish procedure - measured in degrees from the horizontal plane. Sign will be assigned by the program, regardless of the sign of the input value.

PART III: DESCRIPTION AND EXPLANATION OF PRINTED OUTPUT TABLES (Wright 1991)

Types of Output Tables

133. Thirty-nine different types of output tables are printed by UTEXAS3. The forms of these tables and the information which they contain are described in this section. Each type of table is identified by a table number for reference and identification. The table number is printed on the computer output at the start of each table. The table number corresponds to the type of information which the table contains. Tables are printed in the order in which the information contained in the tables are either input to, or generated by, the computer program. Accordingly, tables will not necessarily be printed in the order of ascending or descending table numbers. Some tables may not be printed at all, and other tables may be printed several times, depending on the type of data which are input and the program options which are used.

134. Most of the tables start on a new page of output and a two-line header containing information about UTEXAS3. The header will also usually include the date and time[2]. The next three lines on the output contain the heading which the user has entered as Group A data. A table number in accordance with the numbering system described in this section is then printed. For most tables a descriptive banner will be printed immediately following the table number. The banner for conventional, single-stage analyses or the first-stage of two-stage analyses, will be enclosed by a rectangle of asterisks (*** etc.). For example the banner for Table 3, the material properties would appear as:

```
*******************************************************************
* NEW MATERIAL PROPERTY DATA-CONVENTIONAL/FIRST-STAGE COMPUTATIONS *
*******************************************************************
```

In the case of information for the second-stage of the stage computations a similar banner is printed, except that the rectangle framing the banner is printed as two's (222 etc). For example, the banner for Table 3 containing

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[2]This depends on the specific computer system being used and whether the system clock is accessed by UTEXAS3.

material properties for the second stage of two-stage computations would be printed as:

```
2222222222222222222222222222222222222222222222222222222222222222222
2      NEW MATERIAL PROPERTY DATA - SECOND-STAGE COMPUTATIONS     2
2222222222222222222222222222222222222222222222222222222222222222222
```

Asterisks (*** etc.) and two's (222 etc.) are also used in the banners for information computed as part of the solution by UTEXAS3. Asterisks (*** etc.) are used in the banners for conventional computations and the first stage of two-stage and three-stage computations. Two's (222 etc.) are used for the banners for computed results from the second stage of two-stage and three-stage computations. When three-stage computations are performed three's (333 etc.) are used with the banner for information computed during the third stage of the computations.

Description of Output Tables

135. The first output table (Table 1) contains general information pertaining to the computer program and is printed only once at the start of program execution. The next fifteen tables (Table Nos. 2 through 16) contain data which are used to define the problem. All of these fifteen tables, with the exception of Table 16, contain data which are input by the user; Table 16 contains slope coordinate geometry data generated, optionally, by the computer program. Each of these fifteen tables (2 through 16) is printed separately any time the specific data contained in the table is changed by new input data. If a specific set of data is not changed, the corresponding table will not be printed. The remaining twenty-three tables (Tables 17 through 39) contain information which is generated by the program during computations. These twenty-three tables contain intermediate information, as well as the final solution. The contents of all thirty-nine output tables are described in further detail below.

Table 1 - Program Header

136. Table 1 contains the computer program header message: the program name (UTEXAS3) and the version number of the program. Table 1 also contains the copyright notice and a disclaimer and warning message. Table 1 is printed only once at the start of execution.

Table 2 - Input Data for Profile Lines

137. This table contains the input data used to describe the profile lines (Group B data). The table is printed every time new profile line data are input to the program and only when new data are input. Any data which have been previously input and are to be retained when the new data are input will not be printed again. Instead a note will be printed to the effect that previous data are retained and the user should refer to earlier output.

Tables 3 and 4 - Input
Data for Material Properties

138. These tables contain the input data for material properties (Group C data). Table 3 contains the data for conventional computations or the first-stage of multi-stage computations; Table 4 contains the data for the second and third stages of multi-stage computations. The tables are printed every time new material property data are input and only when new data are input. Any data for materials which are retained from previous input will not be printed again. Instead, a message will be printed to designate the number of materials for which previous data are retained, and the user should refer to earlier printed output tables for the retained data.

Tables 5 and 6 - Input
Data for Piezometric Lines

139. These tables contain the input data for the piezometric lines (Group D data). Table 5 contains the data for conventional computations or the first-stage of multi-stage computations; Table 6 contains the data for the second and third stages of multi-stage computations. The tables are printed every time new piezometric line data are input to the program and only when new data are input. Any data which have been previously input and are to be retained when the new data are input will not be printed again. Instead, a note will be printed to the effect that previous data are retained and the user should refer to earlier output.

Tables 7 and 8 - Input Data
for Pore Pressure Interpolation

140. These tables contain the input data used for interpolation of either pore water pressure or r_u values (Group E data). Table 7 contains the data for conventional computations or the first-stage of multi-stage computations; Table 8 contains the data for the second and third stages of multi-stage computations. The tables are printed whenever these data are

input. If only some of the data are new and some other data input previously are retained, only the new data will be printed. A message will be printed indicating that previous data will not be printed again. The user should refer to earlier printed output for the data which are retained.

Table 9 - Input Data for Slope Geometry

141. This table contains the coordinates defining the slope geometry (Group F data) when the coordinates are specifically defined as input data (see also Table 16). The table is printed whenever the coordinates are defined or redefined by input data. If only some of the coordinates are changed (as in the case of Modify Mode), then only the new coordinates are printed; the coordinates which are not modified are not printed again. This table is printed only when the slope coordinates are defined specifically by Group F input data (see Table 16 for the case where slope coordinates are generated by the program).

Tables 10 and 11 - Input Data for Surface Pressures

142. These tables contain the input data for the pressures acting on the surface of the slope (Group G data). Table 10 contains the data for conventional computations or the first-stage of multi-stage computations; Table 11 contains the data for the second and third stages of multi-stage computations. The table is printed only when these data are defined or redefined by new input data. If only some of the data values are changed by the input data (as in the case of Modify Mode), then only the data values which are changed are printed.

Tables 12 and 13 - Input Data for Concentrated Forces

143. These tables contain the input data for concentrated internal and external forces (Group H data). Table 12 contains the data for conventional computations or the first-stage of multi-stage computations; Table 13 contains the data for the second and third stages of multi-stage computations. The table is printed only when these data are defined or redefined by new input data. If only some of the data values are changed by the input data (as in the case of Modify Mode), then only the data values which are changed are printed.

Table 14 - Input Data for Reinforcement

144. This table contains the input data used to describe the internal soil reinforcement (Group J data). The table is printed every time new soil reinforcement data are input to the program and only when new data are input. Any data which have been previously input are to be retained when new data are input will not be printed again. Instead, a note will be printed to the effect that previous data are retained and the user should refer to earlier output.

Table 15 - Input Data for Analysis/Computations

145. This table contains the information for the analysis and computations which is input by means of Group K data. The table is printed only when new Group K data are input. In addition to containing the values input as data, the table contains values of parameters which either were set as default values by the program or were defined by previous input data.

Table 16 - Slope Geometry Data Generated by UTEXAS3

146. This table contains the slope geometry data and is printed when the slope coordinates are generated by the computer program from the profile line coordinate data. The table is printed every time that the program generates new slope geometry coordinates from profile lines; otherwise the table is not printed.

Tables 17, 18 and 19 - Long-Form of Automatic Search Output (Circles)

147. These tables are the normal output tables printed during an automatic search for a critical circular shear surface. The tables contain the center point coordinates, radius and factor of safety for each trial circle attempted. In addition, a message may be printed for some trial circles. For example, messages are printed to indicate when a circle does not intersect the slope and when the numerical solution for the factor of safety does not converge.

148. Table 17 is printed when the search is being conducted with all circles passing through a given, fixed point; Table 18 is printed when the search is being conducted with all circles tangent to a given, horizontal line; Table 19 is printed when the search is conducted with all circles having the same radius. With the exception of the heading at the top of each of

these tables, the forms of Table Nos. 17, 18 and 19 are identical. When a search is performed to locate the overall most critical circle, several of these tables may be printed and some may be printed more than once. At the conclusion of each mode of search the coordinates of the most critical circle and corresponding values for the factor of safety and side force inclination found in the current mode are printed at the end of each table before continuing to either the next mode or completion of the search.

Table 20 - Short-Form of
Automatic Search Output (Circles)

149. Table 20 is the "Short-Form" output table for an automatic search with circular shear surfaces. The table contains a summary of the most critical circles found for each mode of search. The center point coordinates and radii of the critical circles for each mode are printed with the corresponding minimum factor of safety.

Table 21 - Summary of
Automatic Search (Circles)

150. This table is printed at the conclusion of an automatic search for a critical circular shear surface. The table contains the x and y coordinates of the center point of the critical circle, the radius of the critical circle, and the corresponding minimum factor of safety and side force inclination. The table also contains the number of circles which were attempted and the number of circles for which the factor of safety could be successfully calculated. For example, some trial circles which are attempted may not intersect the slope and, thus, are attempted, but the factor of safety is not calculated.

Table 22 - Preliminary
Automatic Search Information (Noncircular Shear Surface)

151. This table is printed as part of the normal (long-form) of search output at the start of an automatic search for a critical noncircular shear surface. The table contains the value of the crack depth which has been computed based on the initial trial shear surface and slope geometry. The table will also contain any information pertaining to adjustments in the coordinates of the initial trial shear surface if the coordinates lie slightly above the surface of the slope. Finally, the table will contain the factor of safety and side force inclination for the initial trial noncircular shear surface.

Table 23 - Long-Form of Automatic
Search (Noncircular Shear Surfaces)

152. This table is the normal output table printed during an automatic search to locate a critical noncircular shear surface. This table is printed for each new trial position of the noncircular shear surface. One line of information is printed in the table each time that a point on the given trial shear surface is temporarily moved and the factor of safety is computed. Each line contains the temporary x and y coordinates of the point which has been shifted and the corresponding factor of safety and side force inclination along with any messages pertinent to the computations for the particular, temporary shear surface configuration, e.g., "SOLUTION FOR FACTOR OF SAFETY DID NOT CONVERGE WITHIN 40 ITERATIONS." Once all points have been temporarily shifted and the factor of safety has been computed, the newly estimated coordinates for each point on the shear surface are printed, followed by the factor of safety and side force inclination computed for the newly estimated position of the shear surface. A new trial is then initiated, a new Table 23 is printed, and the output begins again as described above.

Table 24 - Summary of Automatic
Search (Noncircular Shear Surfaces)

153. Table 24 is the "Short-Form" output table for an automatic search with noncircular shear surfaces. The table contains the coordinates for each trial position of the shear surface and the corresponding factor of safety, but does not contain the coordinates and factors of safety computed for each temporary move ("shift") of individual point on the shear surface. Table 24 is printed only once for each problem, while Table 23 is printed for each trial position of the shear surface.

Table 25 - Summary of Automatic
Search (Noncircular Shear Surfaces)

154. This table is printed at the conclusion of an automatic search for a critical noncircular shear surface. This table contains the number of trial positions used to locate the critical shear surface, the coordinates of the points defining the critical noncircular shear surface found by the search, the minimum factor of safety, and the corresponding side force inclination.

Tables 26, 27 and 28 -
Individual Slice Information
(Conventional or First Stage Computations)

155. Tables 26, 27 and 28 contain information on the individual vertical slices into which the soil mass is subdivided for computing the factor of safety. These tables contain the information for conventional computations or the first stage of multi-stage computations (See Tables 30, 31, 32 and 33 for information for the second stage of two-stage computations). When individual shear surfaces are specified one by one by the user as input data, these tables are printed for each shear surface. In the case of an automatic search, these tables are printed for only the most critical shear surface. Table 26 contains eight columns of information. The first column contains the slice number. The next two columns contain the x and y coordinates of the left edge, the center, and the right edge of the slice along the shear surface. The center coordinates of the slice are printed on the same line as the slice number and other slice information; the coordinates of the left and right edges of the slice are printed on lines by themselves, above and below the center coordinates, respectively.

156. The fourth column in Table 26 contains the slice weight followed, in the fifth column, by the material type for the material at the base of the slice. The sixth and seventh column contain the cohesion and friction angle for the material at the base of the slice, except when the shear strength envelope is nonlinear; in the case of a nonlinear envelope the words "NON-LINEAR ENVELOPE" are printed in the sixth and seventh columns. The eighth and final column of Table 26 contains the value of the pore water pressure at the center of the base of the slice.

157. Table 27 also contains eight columns of information pertaining to individual slices. The first column contains the slice number. The second column contains the x coordinate of the center of the base (mid-point) of the slice. The third column contains the seismic ("pseudo-static") force computed from the seismic coefficient and the fourth column contains the y coordinate of the line of action of the seismic force corresponding to the x value in the second column. The fifth through eighth columns of Table 27 contain information pertaining to the forces acting on the top surface of each slice due to "surface pressures." The normal and shear (tangential) component

of the forces and the x and y coordinates of the location of the resultant force on the top of the slice are printed in these final four columns.

158. Table 28 contains six columns of information pertaining to soil reinforcement forces for individual slices. This table is only printed when soil reinforcement has been specified in the input data. The first column of the table contains the slice number. The next two columns contain the total horizontal and vertical forces, respectively, on the slice due to <u>all</u> soil reinforcement which intersects the slice. Depending on the option chosen for the reinforcement, the forces will include the reinforcement forces on the sides and base of the slice (Option 1) or only on the base of the slice (Option 2). The fourth column contains the moment produced by the total soil reinforcement force about a point on the center of the base of the slice. The last two columns of the table contain the magnitude and direction of the resultant force due to the soil reinforcement. The magnitude is always expressed as a positive quantity. The direction is expressed as an angle of inclination measured in degrees from the horizontal, with positive angles being measured in the counter-clockwise direction.

159. At the end of Tables 26, 27 and 28 information is printed pertaining to any concentrated forces acting on slices. The information indicates which slice each concentrated force was applied to. If a concentrated force lies outside the limits of all slices, an indication that the force was not assigned is printed. (Note: This is for information only, it is not an error condition.) If no concentrated forces are specified, this information is omitted.

Table 29 - Iterative Solution for the Factor of Safety (Conventional or First Stage Computations)

160. Table No. 29 contains a detailed iteration-by-iteration summary of the trial and error calculations performed during computation of the factor of safety for a given shear surface. This table is printed whenever Tables 26, 27 and 28 are printed, i.e., the table is printed for individual shear surfaces selected by the user, or for the most critical shear surface in the case of an automatic search. The information contained in this table, other than the values for the final factor of safety and side force inclination, is ordinarily only of interest when difficulties are encountered in obtaining a solution for the factor of safety and the iterative solution fails to converge.

In such cases the pattern by which the factor of safety and side force inclination are varying in the iterative solution can be seen and corrective action can often be taken. Corrective action usually consists of altering the initial trial values used for the factor of safety and side force inclination (See Group K data in paragraphs 79 through 132).

Tables 30, 31, 32 and 33 - Individual Slice Information (Second Stage Computations)

161. Table 30 contains seven columns of information pertaining to the computation and assignment of two-stage strengths for the second stage of two-stage stability computations. The first column contains the slice number (this table contains only information for slices that have two-stage strengths). The second and third columns contain the effective normal stress and the shear stress on the shear surface at consolidation, respectively. The fourth and fifth columns contain the shear strengths determined from the R and S envelopes, respectively. The sixth column contains the effective principal stress ratio at consolidation (K_c) computed from the shear and normal stresses on the shear surface. The seventh column contains the effective principal stress ratio at failure (K_f) computed from the effective normal stress on the shear surface and the shear strength parameters for the S envelope. If either the effective minor principal stress ratio at consolidation or at failure is computed to be negative, the effective principal stress ratios are not printed and an appropriate, informative message is printed in the sixth and seventh columns.

162. Tables 31, 32 and 33 contain information about the individual slices for the second stage of two-stage computations. Tables 31, 32 and 33 are directly comparable to Tables 26, 27 and 28, respectively, except that Tables 31 - 33 contain information for the second stage computations. Tables 31, 32 and 33 are printed each time that Tables 26, 27 and 28 are printed for two-stage computations.

Table 34 - Iterative Solution for the Factor of Safety (Second Stage Computations)

163. Table No. 34 contains the same information contained in Table 29 except the information is for the second stage of two-stage computations. This table is not printed for conventional (single-stage) computations.

Tables 35 an 36 - Individual Slice
Information (Third Stage Computations)

164. Table 35 contains five columns of information pertaining to the computation and assignment of strengths for the third stage of three-stage stability computations. The first column contains the slice number (this table contains only information for slices that have two-stage strengths). The second column contains the effective normal stress at the end of the second stage. The effective stress is computed by taking the total normal stress on the base of the slice computed in the second stage stability computations and subtracting the pore water pressure that would exist at for drained conditions. The pore water pressure is computed based on the pore pressure data entered with the two-stage strength data. The third column contains the undrained shear strength which was used for the second stage computations. The fourth column contains the drained shear strength calculated (estimated) using the effective normal stress in Column 2 and the effective stress shear strength parameters ($\bar{c} = d_S$, $\bar{\phi} = \psi_S$). The fifth column contains the word "Drained" or "Undrained" indicating which of the two strengths is lower and is subsequently adopted for use in the third stage stability computations.

165. Table 36 contains information about the individual slices for the third stage of three-stage computations. Table 36 is directly comparable to Tables 26 and 31 for the first stage and second stage computations, respectively, except that Table 36 contains information for the third stage computations. Tables 35 and 36 are printed each time that Tables 26-28 and 30-33 are printed for three-stage computations.

Table 37 - Iterative
Solution for the Factor of
Safety (Third Stage Computations)

166. Table 37 contains the same information contained in Tables 29 and 34 except the information is for the third stage of three-stage computations. This table is not printed for conventional (single-stage) or two-stage computations.

Tables 38 and 39 -
Final Solution Information

167. Tables 38 and 39 contain important information pertaining to the solution of the equilibrium equations for the factor of safety. The tables

are printed whenever Tables 26, 27 and 28 are printed, provided that the solution for the factor of safety has converged.

168. The first portion of Table 38 contains six columns of information with one line of information printed for each slice. The first column contains the slice number followed by the x and y coordinates of the center of the base of the slice in the second and third columns, respectively. A "total" normal stress, "effective" normal stress and shear stress at the center of the base of the slice (shear surface) are printed in the fourth, fifth, and sixth columns, respectively. However, what is labeled as "total" and "effective" is not in all cases what may be implied by these labels as noted below:

a. The "total" normal stress printed in the fourth column will actually be the effective normal stress if submerged unit weights are used for the soil; otherwise the stress printed in the fourth column is the actual total normal stress.

b. The "effective" normal stress printed in the fifth column is actually the "total" normal stress, minus any value of pore water pressure which has been defined by input data. Thus, in the case of total stress analyses, where no pore water pressures are specified, the "effective" normal stress printed in Table 38 will actually be the same as the total normal stress.

Compression is considered to be positive for the normal stresses; tension is considered to be negative. The shear stress is considered to be positive when it acts on the shear surface in a direction opposite to the direction of potential sliding of the soil mass; any reasonable value of shear stress should be positive.

169. Table 39 contains information pertaining to the forces between slices and is printed when Spencer's procedure, the Corps of Engineers' Modified Swedish procedure, and Lowe and Karafiath's procedure are used to compute the factor of safety. Table 39 is not printed for the Simplified Bishop procedure. The first three columns of Table 39 contain the same type of information, regardless of the procedure employed. The first column contains the number of the slice. The second column contains the x coordinate of the right-hand side of the slice. The third column contains the total resultant side force at the right side of the slice; the resultant represents the resultant of the vertical and horizontal components of the side force.

170. The remaining columns (after the first three columns) in Table 39 vary depending on the specific procedures used to compute the factor of safety as follows:

a. Spencer's procedure. In the case of Spencer's procedure, column four contains the y coordinate of the point of application of the resultant side force on the right side (vertical boundary) of the slice. The fifth column printed for Spencer's procedure contains additional information pertaining to the location of the side force on the vertical slice boundary as follows:

   - A numerical value, e.g., 0.331, will be printed in the fifth column when the side force acts as a point on the boundary which lies between the shear surface and the surface of the slope. In such cases the numerical value which is printed is the fractional distance above the shear surface to the point where the side force acts, expressed as a fraction of the total height of the vertical slice boundary. Thus, if the side force acts at the lower-third point of the slice boundary, a value of 0.333 will be printed. If the side force acts below the shear surface, the word "BELOW" is printed in the fifth column; if the side force acts above the surface of the slope, the word "ABOVE" is printed in the fifth column.

   The final two columns (6 and 7) printed in Table 39 contain values of the stresses acting normal to the vertical slice boundary (i.e., horizontal stresses) at the top and bottom of the slice. These stresses are computed using the magnitude and location of the resultant side force and assuming a linear variation of stress with depth along the vertical boundary between slices. These stresses are seldom of any practical use and may not be valid.

b. Corps of Engineers' Modified Swedish and Lowe and Karafiath's procedures. In the case of these procedures, which only satisfy force equilibrium, the fifth column of Table 39 contains the side force inclination. Table 39 has only five columns for these procedures.

171. Following the information described above for Tables 38 and 39 each of the tables contains additional, identical information pertaining to an automatic check of the solution and possible caution and warning messages. The first set of information which is printed at the end of both Tables 38 and 39 consists of four "check-sums" for forces and moments, which are computed to verify the correctness of a solution. The values of the check-sums should all be small and not exceed values of the force and moment imbalances which are used as solution tolerances in the iterative calculations for the factor of safety and side force inclination. (Note: Default values are used for these solution tolerances unless reset as part of the Group K data.)

172. The final set of information printed at the end of Tables 38 and 39 consists of warning and caution messages when certain conditions are detected in a solution; messages are not printed when no such conditions are detected. Caution level messages are designated by the word "CAUTION" and are printed when tensile stresses are detected from a solution for the upper portion of a shear surface near the crest (top) of the slope. Such tensile stresses may or may not be permissible, depending on the nature of the problem (e.g., short-term versus long-term stability) and the nature of the materials involved (e.g., a clean sand versus a cemented soil). Tensile stresses should only be accepted with caution. Warning level messages are designated on the printed output by the word "WARNING" and are printed either when tensile stresses are calculated in areas near the toe of the slope or when the shear stress acts in an apparently incorrect direction. Warning messages are printed twice for each warning and in most such cases the solution should be rejected.

PART IV: GRAPHICS

173. The graphics (August 1991) with UTEXAS3 provide for displaying the input data and a single shear surface input by the user or the final shear surface from a search. When the program UTEXAS3 is executed, the user is prompted for the name of the input file. The file name with default file extensions are proposed for the output files. The user can either accept the default names or change to suitable names. Once the data file is read and all data error checking has been successfully completed plus the file contains the command word PLOT, the user is asked if a plot of the input data is desired. If there are errors in the data file, plots will not be created. After the analyses are performed, the user will again be asked if a plot is wanted. The graphics programs are set up to work with color graphic monitors up to VGA resolution.

174. Hardcopy plots of the screen graphic can be obtained with this version of the program. Two memory resident printer screen drivers are provided with the software. One print screen driver operates with HP-Laser Jet printers while the other operates with dot matrix printers. The appropriate screen driver must be loaded before the program is initiated. This can be done with commands at the DOS level or by executing a batch program. Once the graphic screen contains the information for which a plot is desired, the user hits the print screen key or key sequence to obtain a plot.

175. The initial graphics display consists of the soil profile data. Figure 9 shows an example of this plot which covers the entire range of X values. There are several options available for enhancing the plot by changing the scale or displaying the data associated with the command words. The following list of options and associated letters used to select the option is shown below. The last option listed ends the graphic session.

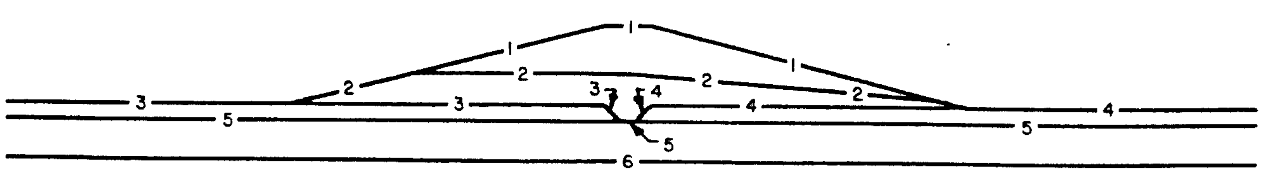


Figure 9. Plot of profile data for entire range of X values

Valid Letter	Option
L	Displays all normal surface loads
S	Displays the slope geometry data
P	Displays all piezometric profiles
I	Displays the interpolation points
F	Displays shear (failure) surface generated by the program
T	Erases current plot and replots the entire soil profile
B	Displays data with different scale factors in the X and Y directions in order to provide the largest possible plot
W	Defines a window for enlarging a portion of the plot
E	Exits graphics and performs analysis
Q	Exits graphics and the stability program returning the user to the DOS command line

The options are selected by entering the appropriate letter and entering a return. If a character other than those in the above list is entered, the program will indicate an invalid character and display the list of options.

176. Figures 10 and 11 show example plots illustrating the piezometric profiles and the normal surface loads. Figure 12 illustrates the slope geometry data for a cut slope example. For the embankment shown in the previous figures, the slope geometry data coincide with an existing soil profile. The plotting of this data over the soil profile results in being unable to read the profile numbers. Figure 13 shows an example plot for the pore pressure interpolation points. Figure 14 shows the initial, noncircular shear surface while Figure 15 shows the final surface after the search procedure. For circular shear surfaces, only the final surface from a search can be plotted. An example of this is shown in Figure 16. On these figures, the space between the profile data and the shear surface is the representation of the tension crack. Both Figures 15 and 16 were plotted after the analysis during the second plotting opportunity.

177. The window option is used to enlarge selected areas of the total cross section. For example, Figure 9 shows the entire cross section while Figure 10 shows just the embankment. The window option was also used for a

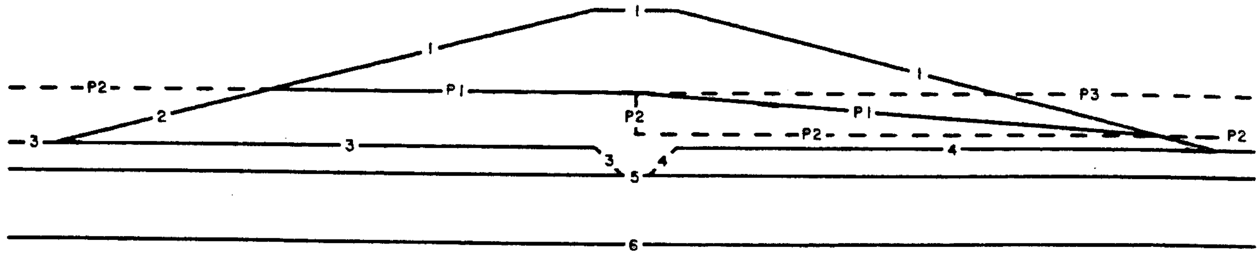


Figure 10. Plot illustrating piezometric profiles

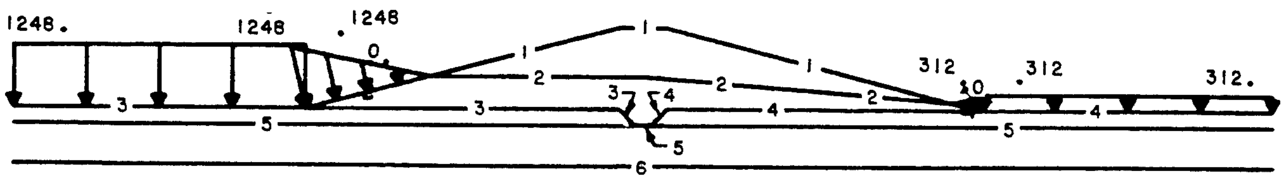


Figure 11. Plot illustrating normal surface loads

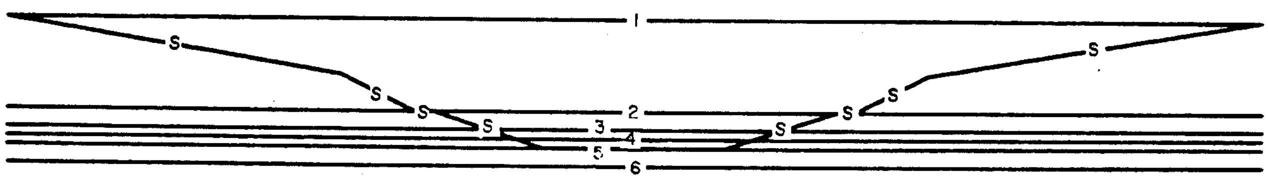


Figure 12. Plot illustrating slope geometry for a cut slope

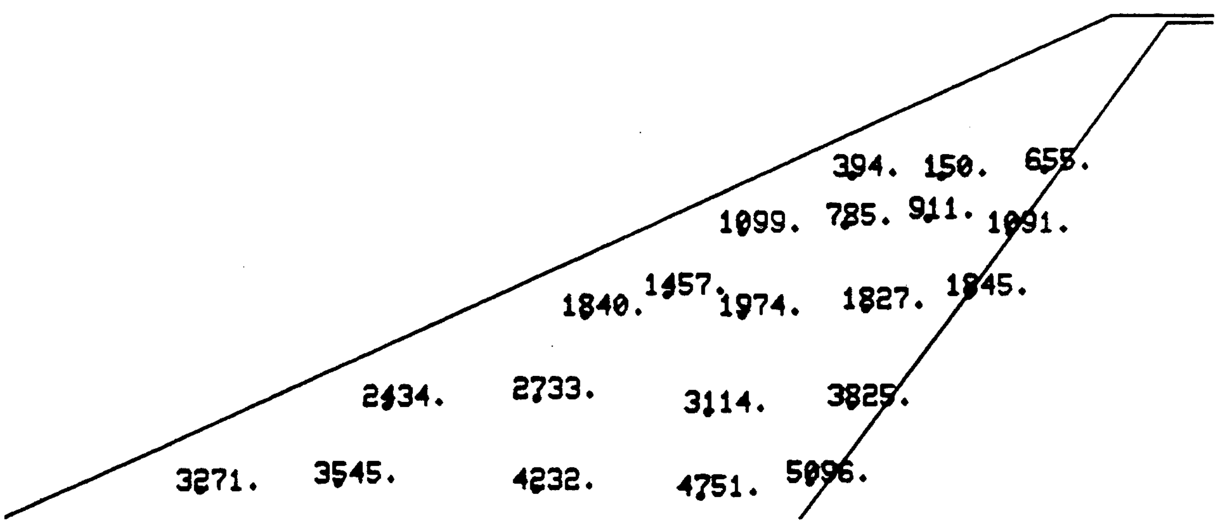


Figure 13. Plot for pore pressure interpolation points

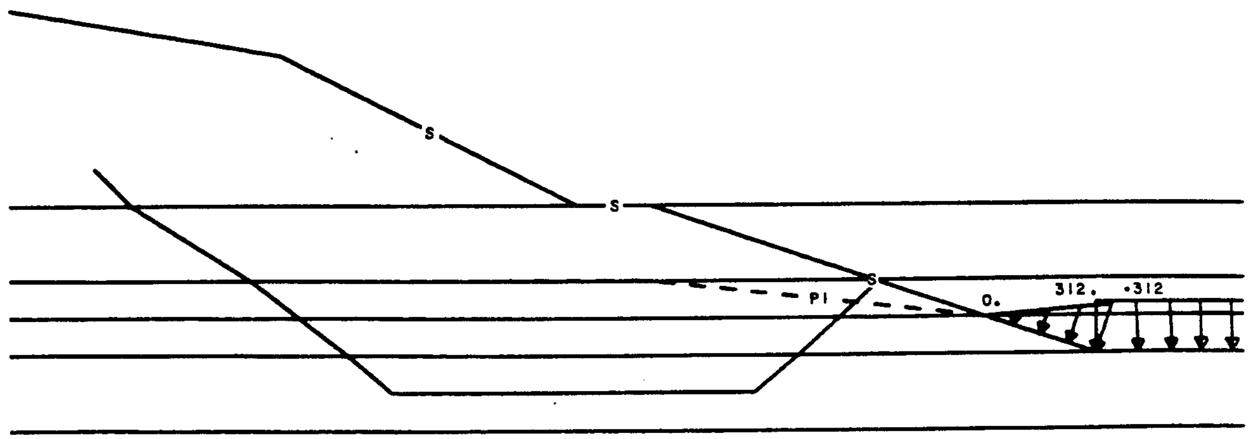


Figure 14. Plot of initial, noncircular shear surface

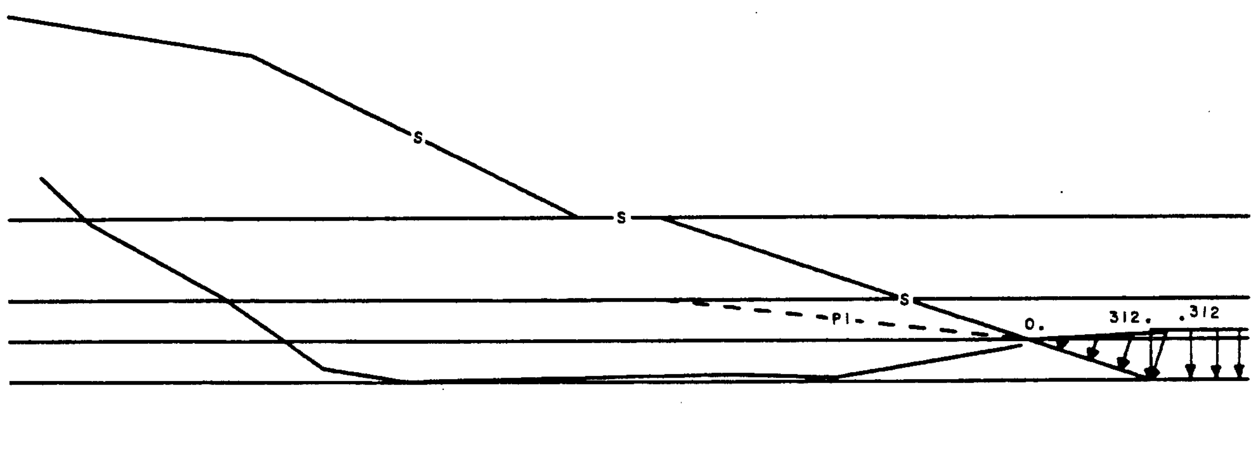


Figure 15. Plot of final surface, noncircular shear surface
after search procedure

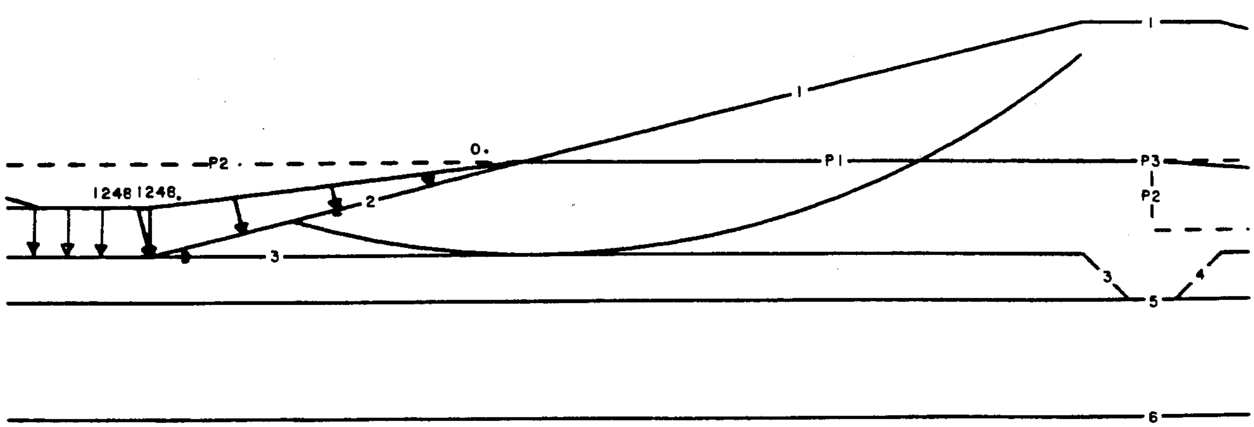


Figure 16. Plot of final surface after search procedure

number of the other figures. To use this option, the plus sign representing the cursor must be moved to the lower left corner of the window area. Then enter the letter "W" and return. The program will display the letters "LL". The plus sign is then moved to the upper right corner of the window, where any character is entered and then the return. After this second letter is entered, the screen is erased and the soil profile within the window is plotted. The user must then redraw the other options of interest.

178. Figure 17 illustrates a different scale option that provides the largest possible plot of the entire cross section. All profile and load data can be plotted on this type of plot. The "T" option is used to erase the screen and plot the entire soil profile again. This option is used to move between window plots, distorted section plots, and entire cross section plots.

179. When the user has completed all the plots and executed the "E" option, the program will then execute the stability analysis if the next command word is "COMPUTE". The "Q" option is used if the user wants to end the program to modify or correct the input data.

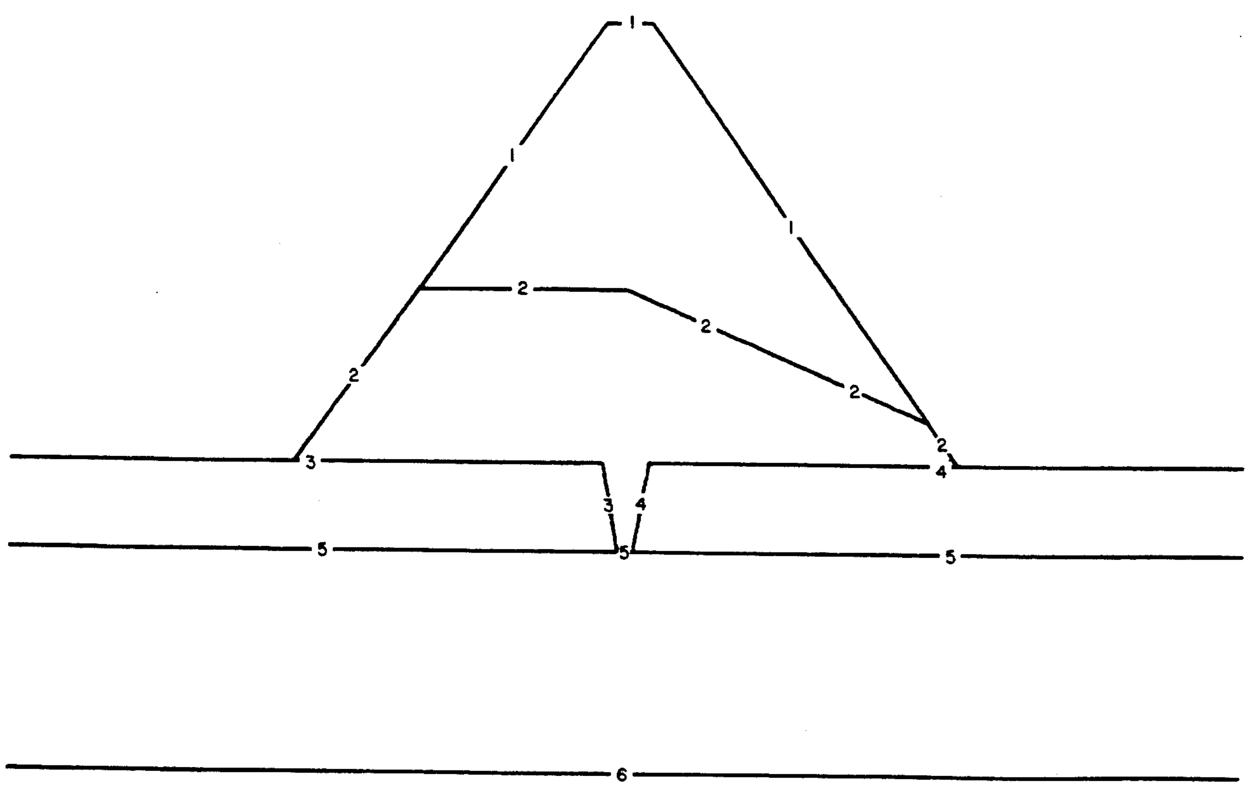


Figure 17. Scale option providing largest plot of cross section

PART V: CONCEPTUAL EXAMPLES

Purpose of Examples

180. The following examples are presented to illustrate the use of UTEXAS3. The first four examples are repeated from Volume I of this series while the last two examples illustrate the new program capabilities. The most usable options are presented in the following paragraphs. Volume III, consisting of example problems illustrating coding procedures for generic problems show the capabilities and the versatility of the new program. For the six examples in this section, the first two examples, an embankment and cut slope, are simple problems illustrating the minimum data file necessary to perform either a singular circular analysis or a noncircular analysis. The third and fourth examples, two loading conditions for an embankment and one loading condition for a cut slope, illustrate the searching capabilities of the program. Several parameters associated with the searching techniques are varied to illustrate their sensitivity. The last two examples illustrate the multi-stage computation and single layer reinforcement capability.

Example 1: Embankment - Single Circular Analysis

181. This simple example describes the end-of-construction loading condition for a homogenous cohesive embankment on a dry sand foundation. The cross section and material properties are shown in Figure 18. This example represents the minimum data configuration to analyze a single circular shear surface.

182. The geometry is represented with two profile lines which in turn reference each material. Since this is a total stress analysis, there are no pore pressures. Also, conventional Q shear strengths are used to specify the cohesion and friction parameters. The analysis data specifies the center point of the circle and the radius. For this problem, given the coordinates of the center of the circle, the radius is specified by defining a point along the circle. Other options for defining the radius are specifying a horizontal elevation to which the circle would be tangent and specifying the radius itself. The complete input file is shown in Figure 19. Since the embankment

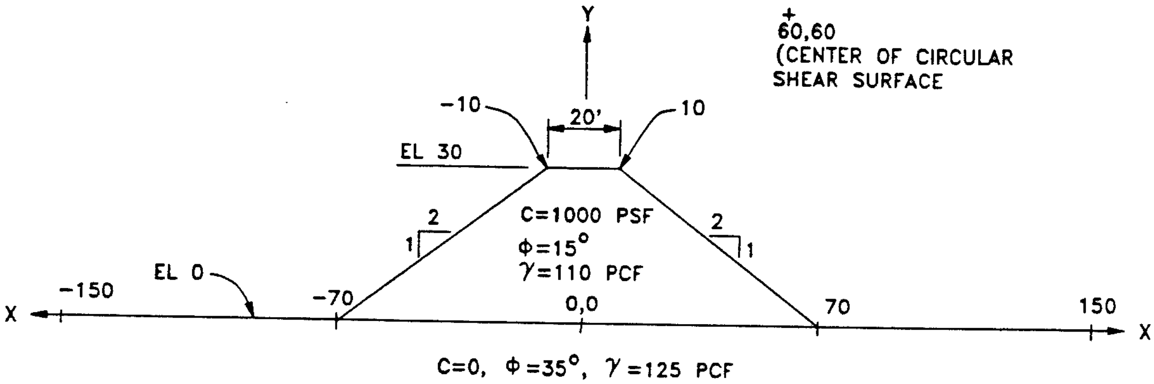


Figure 18. Example 1: Cross Section

heading page 21

```
HEADING                          <- command word
  Example 1 - Simple example
   End of construction loading
   Single circular shear surface
```

profile line data page 22

```
PROFILE LINES                    <- command word
  1   1   Embankment
 -70   0
 -10   30
  10   30
  70   0
                  } blank line
 2   2   Foundation
-150   0
 150   0
                  } 2 blank lines
```

material property data page 26

```
MATERIAL PROPERTIES              <- command word
  1 Embankment clay
  110 = unit weight
  Conventional shear strength
   1000   15
  NO pore pressures
  2  Foundation sand
  125 = unit weight
  Conventional shear strength
   0   35
  NO pore pressure
                  } blank line
```

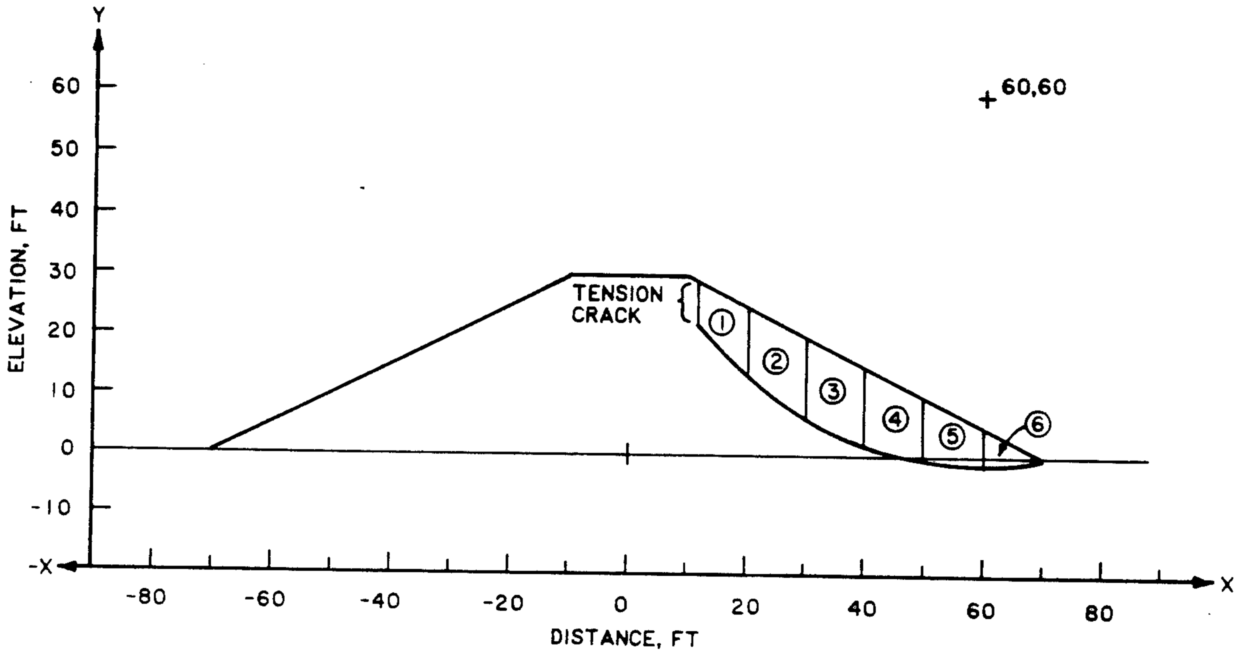
analysis/ computation data page 69

```
ANALYSIS/COMPUTATION             <- command word
 Circular
  60   60
  Point
   70   0
  CRACK                          <- subcommand word
     6.3                         <- depth of tension crack
                  } blank line
PLOT                             <- command word
COMPUTE                          <- command word
```

Figure 19. Example 1: Input data file

is a clay material, a tension crack is assumed. A 6.3-feet deep tension crack is specified in the ANALYSIS/COMPUTATION data. This depth of crack is the maximum anticipated depth of a tension crack in this material. The user is referred to Volume II of the User's Guide for details about tension cracks. The default analysis procedure (Spencer's procedure) is used. The safety factor for the specified circle is 2.90. The computer results are included as file EXAM1.OUT in Appendix E.

183. Figure 20 shows the shear surface and the hand check for this circle. The Corps of Engineers Modified Swedish side-force inclination assumption (Headquarters, Department of the Army 1970) was used with the force equilibrium procedure to perform the hand check. To check the Spencer procedure, the side-force inclination calculated by the Spencer procedure was used for the force equilibrium calculation. The acceptable error of closure for the hand check must be less than the maximum sum of forces used in the computer calculations. The UTEXAS3 input and output files for the Corps procedure, EXAM1H, are included in Appendix E.



Slice Coordinates

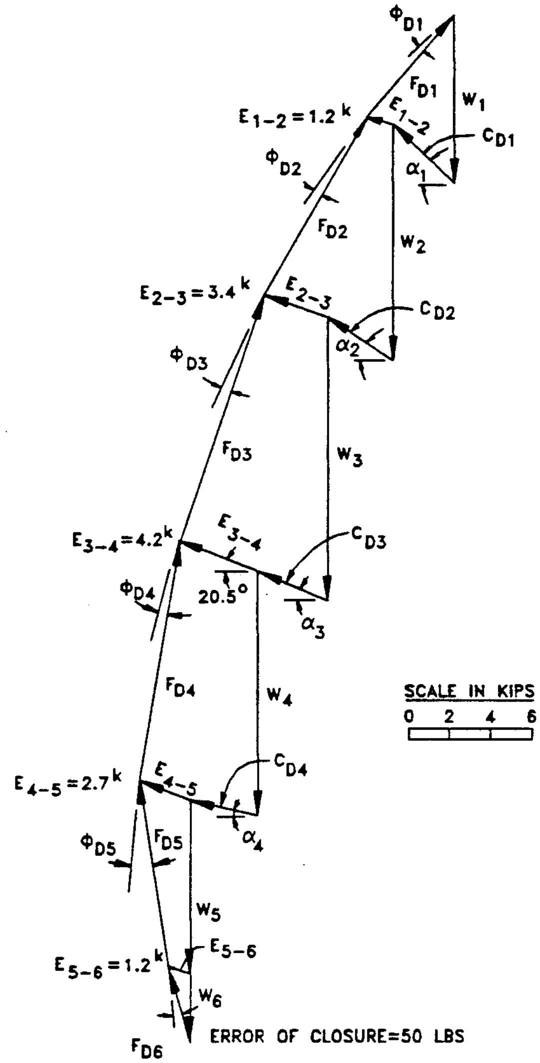
slice	X	y top	y bottom
	11.9	29.05	22.7
1			
	20.7	24.65	13.6
2			
	29.8	20.10	7.2
3			
	40.0	15.0	2.6
4			
	50.0	10.0	0.0
5			
	60.0	5.0	-0.8
6			
	70.0	0.0	0.0

Material Properties

Material	C(psf)	ϕ	C_D(psf)	ϕ_D	γ(pcf)
Embankment	1000	15°	345	5.3°	110
Foundation	0	35°	0	13.6°	125

Trial FS = 2.90

Figure 20. Example 1: Shear surface and hand check (Continued)



FORCE POLYGON DATA

SLICE	SLICE WIDTH, b (FT)	WEIGHT W (KIPS)	α	ΔL (FT)	C_D (k/FT)	Φ_D
1	8.8	8.4	46.0°	12.7	4.38	5.3°
2	9.1	12.0	35.1°	11.1	3.83	5.3°
3	10.2	14.2	24.3°	11.2	3.86	5.3°
4	10.0	12.3	14.6°	10.3	3.55	5.3°
5	10.0	8.8	4.6°	10.0	--	13.6°
6	10.0	3.3	−4.6°	10.0	--	13.6°

NOTES:

SIDE FORCE INCLINATION = 20.5° (FROM RESULTS OF SPENCER PROCEDURE ANALYSIS)

b = HORIZONTAL WIDTH OF SLICE

α = ANGLE OF SLICE BASE WITH HARIZONTAL

ΔL = LENGTH OF SLICE BASE, BASE/COS α

CD = DEVELOPED COHESIVE FORCE, $C_D = \Delta L$

Figure 20. (Concluded)

Example 2: Cut Slope - Single Noncircular Analysis

184. This simple example describes the undrained loading condition for a cut slope. The cross section and material properties are shown in Figure 21. This example represents the minimum data configuration to analyze a single noncircular shear surface using the slope geometry data.

185. The geometry is represented by three horizontal profile lines with the slope defined by the slope geometry data. Each profile line references a material with different profile lines referencing the same material. Since this is a total stress analysis, there are no pore pressures. Also, conventional Q shear strengths are used to specify the cohesion and friction parameters. The noncircular analysis data specifies the points used to define the shear surface. For this problem, four points were used to specify the shear surface. A 6.7-feet deep tension crack is assumed by beginning the noncircular shear surface at the bottom of the crack. This depth of tension crack is the maximum anticipated depth in this material. The user is referred to Volume II of the User's Guide for details about tension cracks. The default analysis procedure (Spencer's procedure) is used. The safety factor for the specified shear surface is 1.41. The computer results are included as file EXAM2.OUT in Appendix E. The complete input file is shown in Figure 22.

186. Figure 23 presents the hand check for this shear surface. The Corps of Engineers Modified Swedish side-force inclination assumption, EM1110-2-1902 (Headquarters, Department of the Army 1970), was used with the force equilibrium procedure to perform the hand check. The side-force inclination calculated by the Spencer procedure was used for the force equilibrium calculations. The UTEXAS3 input and output files for the Corps procedure, EXAM2H, are included in Appendix E.

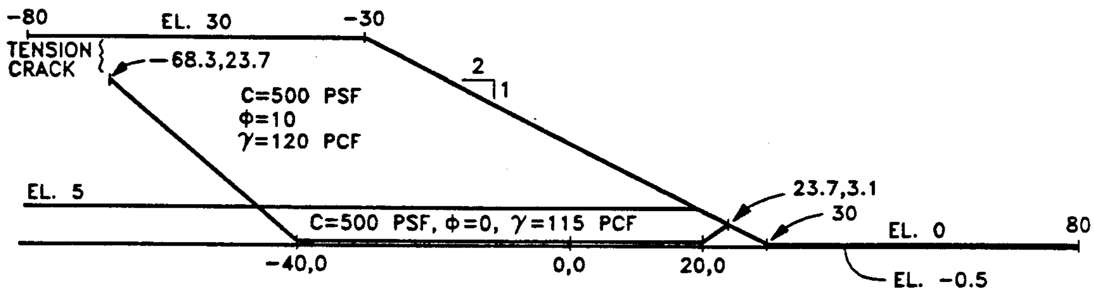
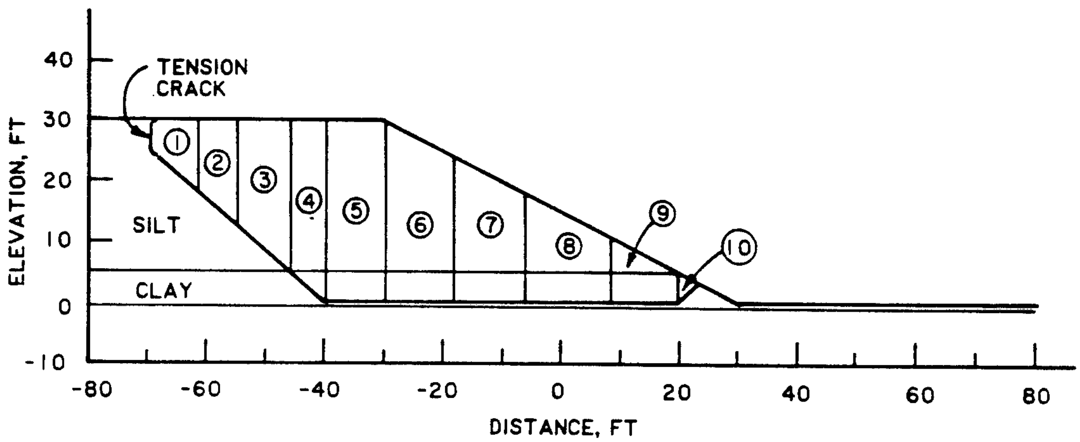


Figure 21. Example 2: Cross Section

```
heading            HEADING  <------ command word
page 21              Example 2 - Simple cut slope example
                      Undrained condition
                      Single noncircular shear surface
                   PROFILE LINES  <------ command word
                     1   1   Silt layer
                     -80   30
                      80   30
                                 blank line
profile              2   2   Clay layer
line data            -80   5
page 22               80   5
                                 blank line
                     3   1   Silt foundation layer
                     -80   -0.5
                      80   -0.5
                                 2 blank lines
                   MATERIAL PROPERTIES  <------ command word
                     1   silt
                      120 = unit weight
                      Conventional shear strength
material               500  10
property              NO pore pressure
data                 2   clay
page 26               115 = unit weight
                      Conventional shear strength
                       500   0
                      NO  pore pressure
                                 blank line
                   SLOPE GEOMETRY  <------ command word
slope geometry       -80   30
data                 -30   30
page 51               30    0
                      80    0
                                 blank line
                   ANALYSIS/COMPUTATION  <------ command word
                     Noncircular
analysis/             -68.3   23.7
computation           -40      0
data                   20      0
page 69                23.7    3.1
                                 2 blank lines
                   PLOT  <------ command word

                   COMPUTE  <------ command word
```

Figure 22. Example 2: Input data file



Slice Coordinates

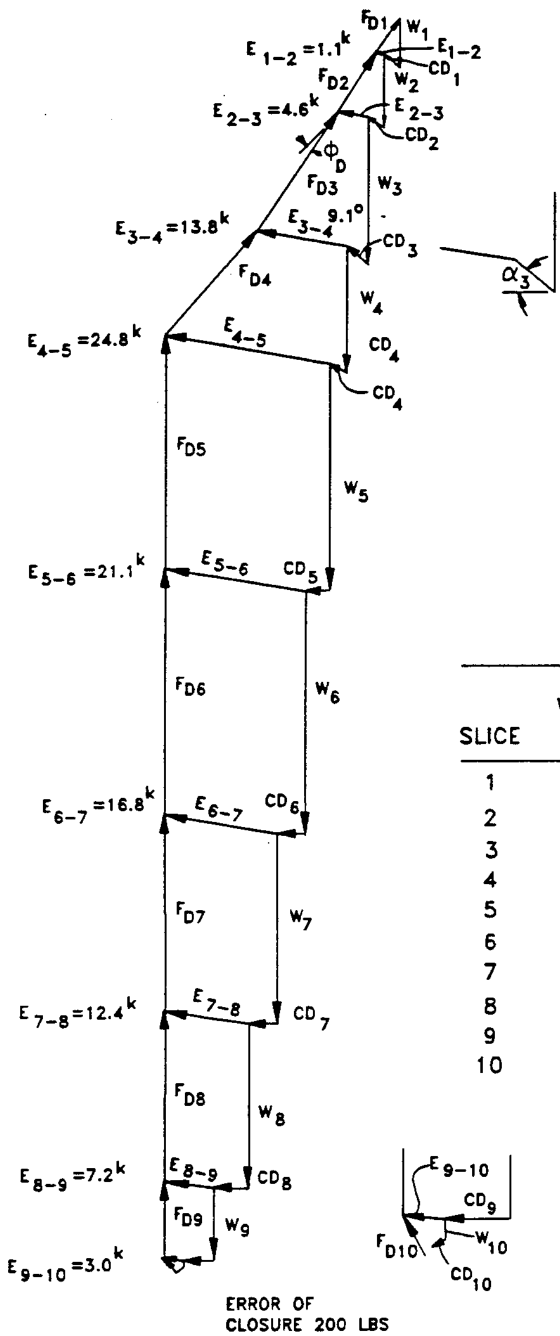
slice	X	y top	y bottom
	-68.3	30.0	23.7
1			
	-61.6	30.0	18.1
2			
	-54.9	30.0	12.5
3			
	-46.0	30.0	5.0
4			
	-40.0	30.0	0.0
5			
	-30.0	30.0	0.0
6			
	-18.2	24.1	0.0
7			
	-6.5	18.25	0.0
8			
	8.2	10.9	0.0
9			
	20.0	5.0	0.0
10			
	23.7	3.1	3.1

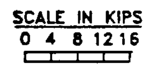
Material Properties

Material	C(psf)	ϕ	C_D(psf)	ϕ_D	γ(pcf)
Silt	500	10°	357	7.2°	120
Clay	500	0	357	0	115

Trial FS = 1.4

Figure 23. Example 2: Hand check (Continued)





FORCE POLYGON DATA

SLICE	SLICE WIDTH, b (FT)	WEIGHT W (KIPS)	α	ΔL (FT)	C_D (k/FT)	ϕ_D
1	6.7	7.3	39.9°	8.7	3.11	7.2°
2	6.7	11.8	39.9°	8.7	3.11	7.2°
3	8.9	22.7	39.9°	11.6	4.14	7.2°
4	6.0	19.7	39.9°	7.8	2.78	0
5	10.0	35.8	0	10.0	3.57	0
6	11.8	38.0	0	11.8	4.21	0
7	11.7	29.4	0	11.7	4.18	0
8	14.7	25.3	0	14.7	5.25	0
9	11.8	11.0	0	11.8	4.21	0
10	3.7	1.1	−39.9°	4.8	1.71	7.2°

NOTES:

SLIDE FORCE INCLINATION = 9.07° (FROM RESULTS OF SPENCER PROCEDURE ANALYSIS)

b = HORIZONTAL WIDTH OF SLICE

α = ANGLE OF SLICE BASE WITH HORIZONTAL

ΔL = LENGTH OF SLICE BASE, BASE/COS α

C_D = DEVELOPED COHESIVE FORCE, C_D = ΔL

Figure 23. (Concluded)

Example 3: Embankment - Circular Search

187. Stability computations for both end-of-construction and partial pool loading conditions are performed for this example problem. The type of shear strength values required in EM 1110-2-1902 (Headquarters, Department of the Army 1970) are used for the appropriate loading conditions. Only circular shear surfaces are considered. Searches for the critical surface using each of the four analysis procedures are presented for both loading conditions along with details on how to perform the search procedure. The end-of-construction loading, case 1, illustrates the circular search sequence, and the effect of the different initial search modes, different starting points, the final grid spacing, and tension cracks. The partial pool loading, case 2, illustrates the incorporation of water loads and different piezometric levels into the analysis. A hand check for one analysis procedure of each loading condition will also be presented.

Embankment description

188. This example consists of a compacted impervious embankment on a sand and clay foundation with an impervious key trench through the sand layer. A cross section of the embankment and foundation is shown in Figure 24. The embankment is 50 feet high with a 1 (vertical) to 4 (horizontal) side slopes. The sand layer, 10 feet thick, and the foundation clay, 25 feet thick, is underlain by rock. The coordinate axes selected for this problem and the corresponding embankment coordinates are included in Figure 24. Table 25 lists the various unit weights and shear strength values for the material in this problem.

189. The geometry for this problem can be represented by five or six profile lines, depending on the hydrostatic loading for the particular condition being analyzed. The profile lines represent the upper boundary of a soil layer with a material under the line identified by the material type. Figures 25a and 26 show the embankment representation for each loading condition. The embankment material is represented as the first profile line. This profile extends only from embankment toe to toe, not over the entire profile. The second profile line represents the sand layer under the upstream portion of the embankment. Because the sand layer does not extend under the key trench and the program does not allow soil layers with zero thicknesses,

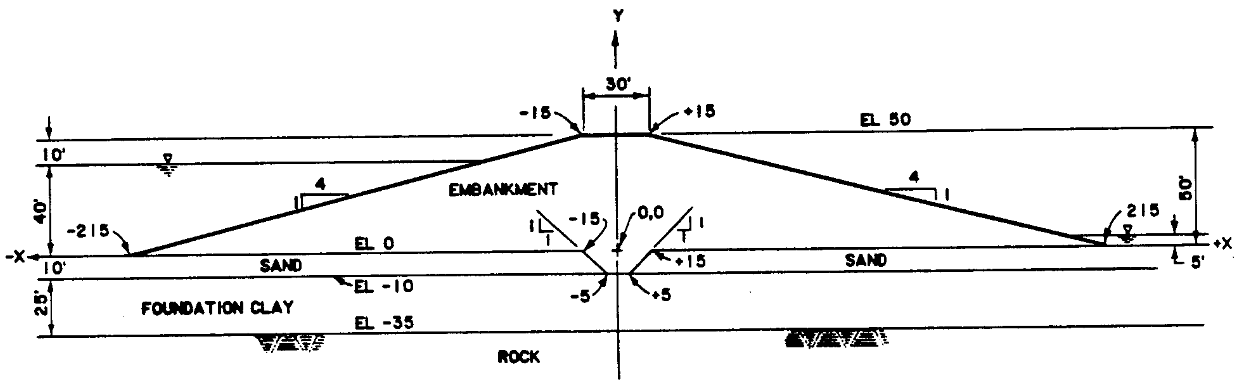
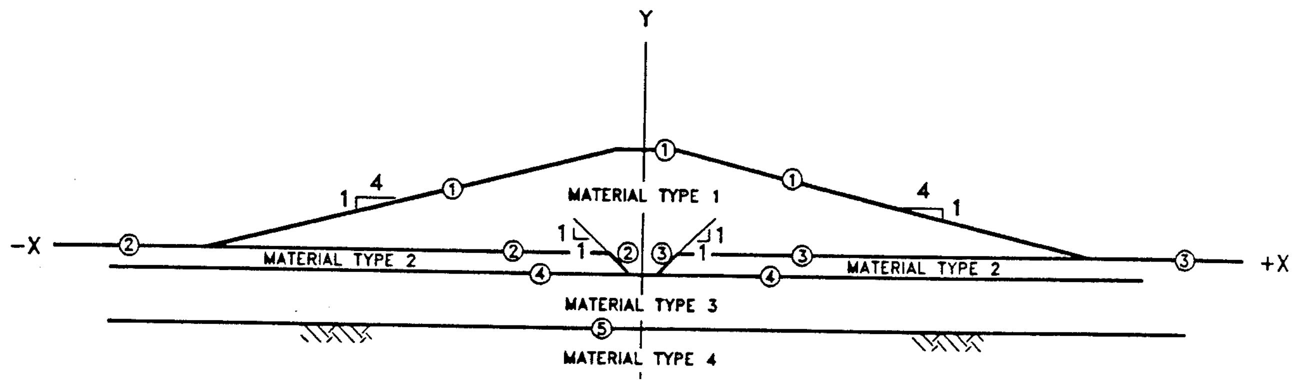


Figure 24. Example 3: Cross section

Table 25
Soil Properties for Example 3

			Q		R		S	
	γ_S	γ_M	C	Ø	C	Ø	C	Ø
EMBANKMENT	120	115	1,000	5	200	15	0	25
SAND	130	125	0	35	0	35	0	35
FOUNDATION CLAY	115	110	3,000	0	250	20	0	30
ROCK	165	160	0	45	0	45	0	45



a. Embankment representation profile data

heading page 21

```
HEADING                              command word
 Example 3 - Circular search
  Clay embankment on 10 foot sand layer
  Sand is over 25 foot of clay over rock
PROFILE LINES                        command word
 1   1   Embankment surface
 -215   0
  -15  50
   15  50
  215   0
                blank line
 2   2   Upstream sand layer
 -400   0
  -15   0
   -5 -10
                blank line
 3   2   Downstream sand layer
    5 -10
   15   0
  400   0
                blank line
 4   3   Foundation clay
 -400 -10
  400 -10
                blank line
 5   4   Rock
 -400 -35
  400 -35
                2 blank lines
```

profile line data page 22

b. Profile data for end-of-construction loading

Figure 25. Loading condition for Example 3

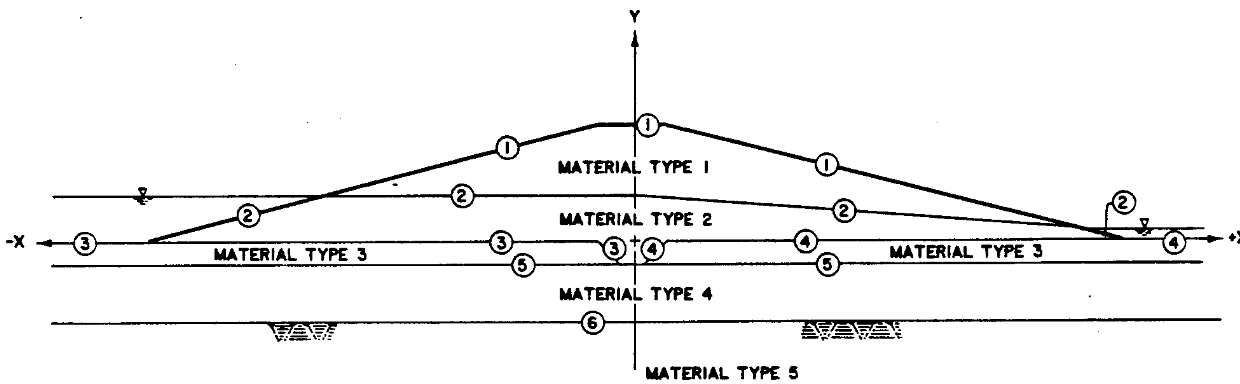


Figure 26. Partial pool case for Example 3

it is recommended that the sand layer be represented as two profile lines. Thus, Profile Line 3 represents the sand layer under the downstream portion of the embankment. The material type would be the same for Profile Lines 2 and 3. The top of the foundation clay is represented by Profile Line 4, while the top of rock is Profile Line 5. If a phreatic surface exists, then the embankment material should be represented as two material types with the phreatic line separating the material types. The profile representing the dry embankment would start at the intersection of the water level and the embankment and continue along the surface to the intersection on the other side. The order that the profile lines are defined is not important, but it is necessary that the lines be defined from left to right in increasing x order. The profile data for the end-of-construction loading is shown in Figure 25b.

Case 1 - End of construction

190. For this case, the Q strength values and the appropriate unit weights listed in Table 25 are used. There is no pore water pressure in the embankment. The ground water level is assumed to be at elevation 0.0 which is the top of the sand layer. Thus, the sand and the foundation clay are saturated with saturated unit weights used in the analyses. The listing of the material property input data is shown as Figure 27. The same piezometric level can be used for different materials.

```
heading         HEADING                                  <-- command word
page 21           Case 1 - End of Construction (Q strength)
                   No pore pressures in embankment
                   Groundwater table elevation 0.0
                MATERIAL PROPERTY                        <-- command word
                  1  Embankment Q strength
                   115 = moist unit weight
                   Conventional shear strength
                     1000  5
                   NO pore pressures
                  2  Sand layer
                   130 = saturated unit weight
                   Conventional shear strength
                     0    35
                   Piezometric Line
material             1  Piez line for groundwater
properties        3  Foundation clay
page 26            115 = saturated unit weight
                   Conventional shear strength
                     3000  0
                   Piezometric Line
                     1  Piez line for groundwater
                  4  Rock
                   165 = saturated unit weight
                   Conventional shear strength
                     0    45
                   Piezometric Line
                     1  Piez line for groundwater
                                                         } blank line
                PIEZOMETRIC LINE DATA                    <-- command word
piezometric       1  62.4   Groundwater table
data               -400     0
page 41             400     0
                                 } 2 blank lines
```

Figure 27. Material property and piezometric line input data

191. For both the end-of-construction and partial pool cases, searches for the critical shear surface were performed. The initial circle center point and final grid spacing were specified. A listing of the necessary analysis data for both a toe and tangent circle is shown in Figure 28. The final grid spacing of 1 percent of the slope height is recommended. Thus, for this example the spacing would be 0.5 feet.

192. There are two types of circular shear surfaces that are analyzed in this case. The first will be for circles passing through the embankment toe. The second type will be circles that are tangent to the base of the

heading page 21	HEADING	*command word*
	Example 3 - case 1	
	Modified Swedish (Corps method)	
	Search for critical shear surface	
analysis/ computation data page 69	ANALYSIS/COMPUTATION	*command word*
	Circular Search	
	101 180 0.5 -60	
	Tangent	
	-1.0	
	PROCEDURE	*subcommand word*
	Corps	
	14.0	
	blank line	
	COMPUTE	*command word*

Figure 28. Analyses data for toe and tangent circles

embankment. The type of circular shear surface search will be dependent upon the initial search mode. All analysis procedures are used for each type of these circular shear surfaces. The minimum factor of safety of each circle type for each analysis procedure based on the starting center of x = 101 and y = 180 is listed in Table 26. For comparisons, the circle coordinates, radius, and side-force inclinations are included in the table. For this example, the material property combination is such that the circles tangent to the base of the embankment are critical. The variation of the safety factor due to the analysis procedure is much greater for the toe circles than the tangent circles. Toe and tangent circles will be different and general trends of safety factors and analysis procedures cannot be inferred for different types of circles. The listing of the safety factor to thousandths in the tables and figures is for illustrative purposes only. The values actually obtained will depend upon the computer utilized for the computation.

193. Tension cracks were not used for the analyses listed in Table 26. However, a caution was listed in most of the outputs (Output Table 28) indicating negative effective or total normal stresses on the shear surface at points along the upper half were encountered. This indicated that a tension crack was needed. The analyses were redone using a tension crack of 7 feet. These results are listed in Table 27. The tension cracks slightly reduce the minimum safety factor.

194. For the toe circles (Table 27), three of the four analysis procedures calculated approximately the same circle. The Corps modified Swedish procedure calculated a circle greatly different. This may indicate a

Table 26

Minimum Safety Factor and Circle Coordinates for Toe and Tangent Circles

Initial Starting Point x = 101 and y = 180, No Tension Crack*

			Analysis Procedures			
					Force Equilibrium	
			Spencer	Bishop	Corps Modified Swedish Side-Force Assumption	Lowe and Karafiath Side Force Assumption
Toe Circles	Minimum factor of safety		3.167	3.181	2.699	3.225
	Circle coordinates	X	116.5	115.5	172.0	117.0
		Y	143.5	145.0	365.5	144.0
	Radius		178.4	179.9	370.8	178.9
	Side-force inclination		8.16°	Horiz	14.0°	Varies
Circles Tangent to Base of Embankment	Minimum factor of safety		2.538	2.538	2.628	2.580
	Circle coordinates	X	101.0	101.0	109.0	105.0
		Y	170.5	170.5	193.0	182.5
	Radius		170.5	170.5	193.0	182.5
	Side-force inclination		7.84°	Horiz	14.0°	Varies

* Final grid spacing is 0.5 feet.

Table 27

Minimum Safety Factor and Circle Coordinates for Toe and Tangent Circles

Initial Starting Point x = 101 and y = 180, 7-foot Tension Crack*

			Analysis Procedures			
					Force Equilibrium	
			Spencer	Bishop	Corps Modified Swedish Side-Force Assumption	Lowe and Karafiath Side Force Assumption
Toe Circles	Minimum factor of safety		3.154	3.168	2.642	3.209
	Circle coordinates	X	116.5	115.5	172.5	117.0
		Y	143.0	144.5	352.5	143.5
	Radius		177.9	179.4	357.2	178.4
	Side-force inclination		8.24°	Horiz	14.0°	Varies
Circles Tangent to Base of Embankment	Minimum factor of safety		2.490	2.491	2.577	2.531
	Circle coordinates	X	102.0	102.0	110.0	105.5
		Y	163.0	163.0	185.0	174.0
	Radius		163.0	163.0	185.0	174.0
	Side-force inclination		8.45°	Horiz	14.0°	Varies

* Final grid spacing is 0.5 feet.

localized minimum value was calculated and not the true minimum for this type of circle. To evaluate if only local minimums were calculated, another search should be performed, starting at a different location. The results from searches initiated at x = 170 and y = 350 are shown in Table 28. The circles tangent to the base of the embankment did not change, indicating that the calculated value is the true minimum. The toe circle analysis did generate lower results indicating that local minimums were calculated in Tables 26 and 27. To verify that the true minimum has been found, several different initial values were used in the search process. Table 29 lists the initial and critical centers. Figure 29 shows the critical shear surfaces listed in Tables 27 and 28 plotted on the cross section for all of the analysis procedures.

195. When performing a circular search, the initial search mode is important because it establishes the sequence of the search. There are three modes that the user could select. They are tangent to a horizontal line, through a particular point, and constant radius. The initial search mode establishes whether a toe circle or an embankment circle will be analyzed. In general, a single critical circle should be determined for any search mode. However, the searching sequence can locate minimums that exist making the search procedure "think" that the minimum value is found when, in fact, only a local minimum has been found. The matrix in Table 30 indicates the sequence that the various search modes were performed for different initial modes. For several cases, the initial mode was varied with no difference in the final results. However, the number of circles analyzed varied. Included in the table is the minimum safety factor for each search mode and the number of circles analyzed. For the cases in Table 30, 91 to 350 circular analyses were performed for each case. Different initial search modes shown in Table 30 illustrate the potential differences in the minimum safety factor that could occur. The constant radius mode is not recommended for the initial mode of search.

196. There are two important input values in the data for the circular search other than the initial mode of search. These values are the accuracy or final spacing of the search grid and the starting point of the search. To illustrate the effect of the grid spacing, several searches were performed

Table 28

Minimum Safety Factor and Circle Coordinates for Toe and Tangent Circles

Initial Starting Point x = 170 and y = 350, 7-foot Tension Crack*

			Analysis Procedures			
					Force Equilibrium	
			Spencer	Bishop	Corps Modified Swedish Side-Force Assumption	Lowe and Karafiath Side Force Assumption
Toe Circles	Minimum factor of safety		2.614	2.569	2.642	2.623
	Circle coordinates	X	171.5	170.0	172.5	172.0
		Y	352.5	334.5	352.5	355.0
	Radius		357.2	340.3	357.2	359.6
	Side-force inclination		11.09°	Horiz	14.0°	Varies
Circles Tangent to Base of Embankment	Minimum factor of safety		2.490	2.491	2.577	2.531
	Circle coordinates	X	102.0	102.0	110.0	105.3
		Y	163.0	163.0	185.0	174.0
	Radius		163.0	163.0	185.0	174.0
	Side-force inclination		8.45°	Horiz	14.0°	Varies

* Final grid spacing is 0.5 feet.

Table 29

Effects of Different Starting Points*

Initial Type of Search	Search Starting Point X	Search Starting Point Y	Final Results Safety Factor	Final Results X	Final Results Y	Final Results Radius	Total Number of Circles Tried	Total Number of Circles Calculated
Tangent to elevation 0.0**	101	180	2.490	102	163	163	95	95
	170	350	2.490	102	163	163	312	312
	50	260	2.490	102	163	163	128	128
	60	150	2.490	102	163	163	91	91
	140	130	2.490	102	163	163	121	121
	180	150	2.490	102	163	163	105	105
Toe circle	101	180	3.154	116	143	177.9	127	94
	170	350	2.614	171.5	352.5	357.2	312	312
	50	260	Indeterminate					
	60	150	Indeterminate					
	140	130	3.151	122.5	134	169	128	97
	180	150	2.614	171.5	351	355.8	307	307

* Spencer's procedure with 7-foot tension crack.

** All elevations (el) cited herein are in feet referred to National Geodetic Vertical Datum (NGVD) of 1929.

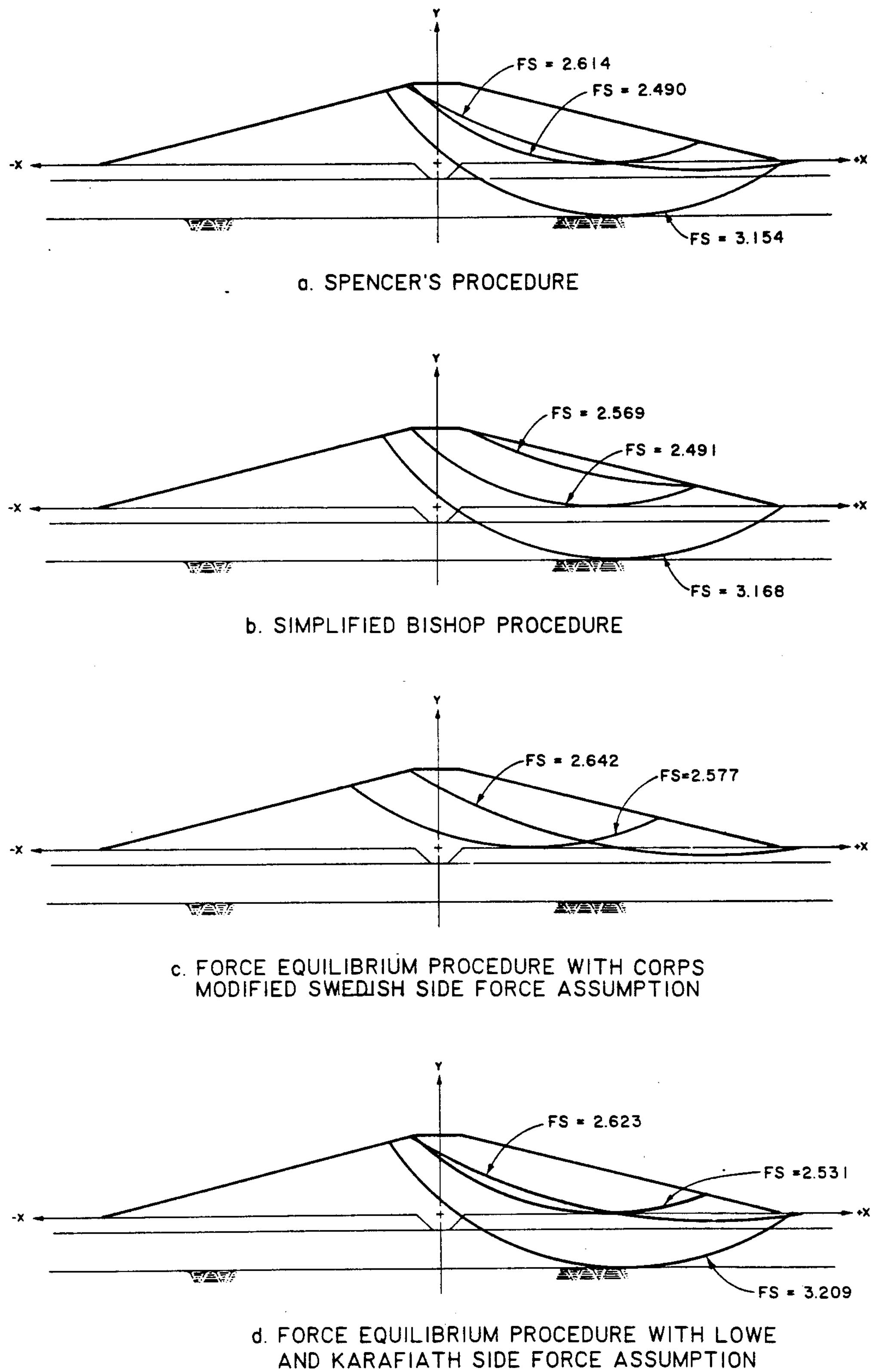


Figure 29. Critical shear surface plotted on the cross section

Table 30

Sequence of Search Modes for Circles Listed in Table 27

Type of Circle	Analysis Procedure		Search Mode: Pass Through Given Point	Search Mode: Tangent to Horizontal Line	Constant Radius	Total Number of Circles: Tried	Total Number of Circles: Calculated
Toe circles	Spencer		1(3.168)	2(3.154)	3(3.154)	127	94
	Bishop		1(3.183)	2(3.168)	3(3.168)	127	94
	Force equilibrium	Corps Modified Swedish side-force inclination EM 1110-2-1902, (Department of the Army 1970)	1(2.651)	2(2.648) 4(2.642)	3(2.643) 5(2.642)	356	350
		Lowe nd Karafiath (1960) side-force inclination	1(3.228)	2(3.209)	3(3.209)	134	101
Circles tangent to base of embankment	Spencer			1(2.490)	2(2.490)	95	95
	Bishop			1(2.491)	2(2.491)	95	95
	Force equilibrium	Corps Modified Swedish side-force inclination EM 1110-2-1902 (Department of the Army 1970)		1(2.577)	2(2.577)	96	96
		Lowe and Karafiath-side-force inclination (1960)		1(2.531)	2(2.531)	91	91

using various initial search modes and varying the final grid spacing. The initial center for all searches was the same, while the final grid spacing was varied from 5 to 1 to 0.5 feet (1 percent of the slope height). The results of these analyses are shown in Table 31 which also includes the final centers and the number of circles analyzed. The initial search mode initiates the sequence of the search which in turn effects the minimum safety factor obtained.

197. The search procedure should arrive at the same point irrespective of the initial center the user selects. However, because of local minimums the user must ensure that the true minimum has been determined. The type of circular analysis depends on the initial search mode selected, the initial search center point, and the final grid spacing. The user should look at several circular searches from different locations with at least one search totally within the embankment. Also, the final grid spacing should be 1 percent of the slope height. The initial search mode and location require engineering input and cannot be done blindly.

198. Both the tangent and radius search modes are illustrated in Figure 30 for the force equilibrium procedure with the Corps Modified Swedish side force inclination. For each center, the order of calculation, the grid spacing interval, and the safety factor are shown. This illustrates the process that the program uses to select the center points. The initial search mode shown in Figure 30a illustrates the process when the critical center value does not fall within the initial grid space. The radius search mode shown in Figure 30b, illustrates the process when the critical center value is located within the initial grid.

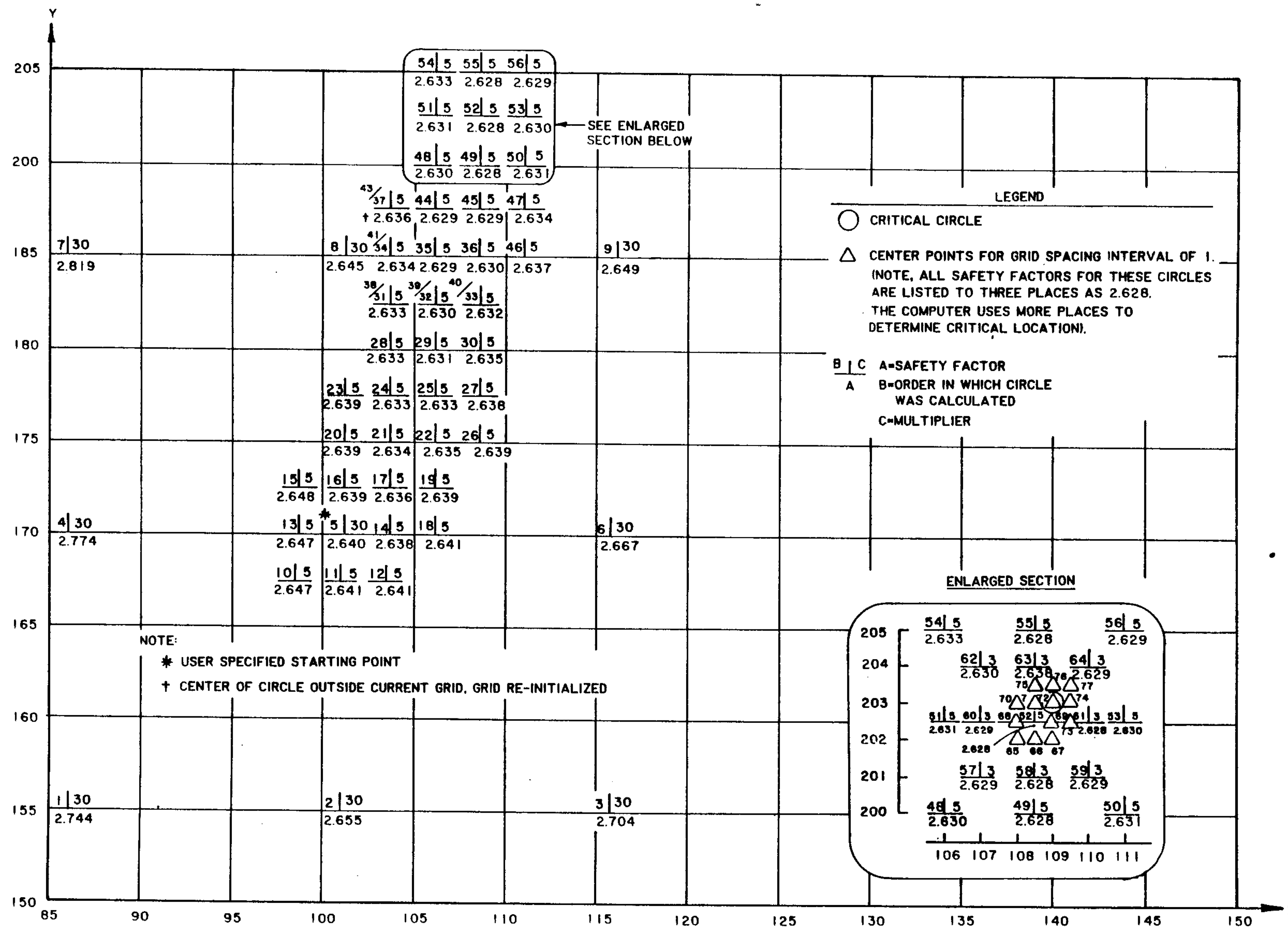
199. The total input data file has been shown in Figures 25, 27, and 28. The computer generated output of the search for the critical shear surface that was tangent to the base of the embankment using Spencer's procedure is included as file EXAM3A.OUT in Appendix E. A graphical hand check of the Spencer results for the final circular shear surface of the search procedure is shown in Figure 31. For this hand check, the side force inclination of 8.45 degrees calculated by Spencer's procedure was used in the construction of the force polygons. All slices and forces were calculated independently of the computer analyses. An independent verification of the Bishop procedure is

Table 31

Effects of Final Grid Spacing*

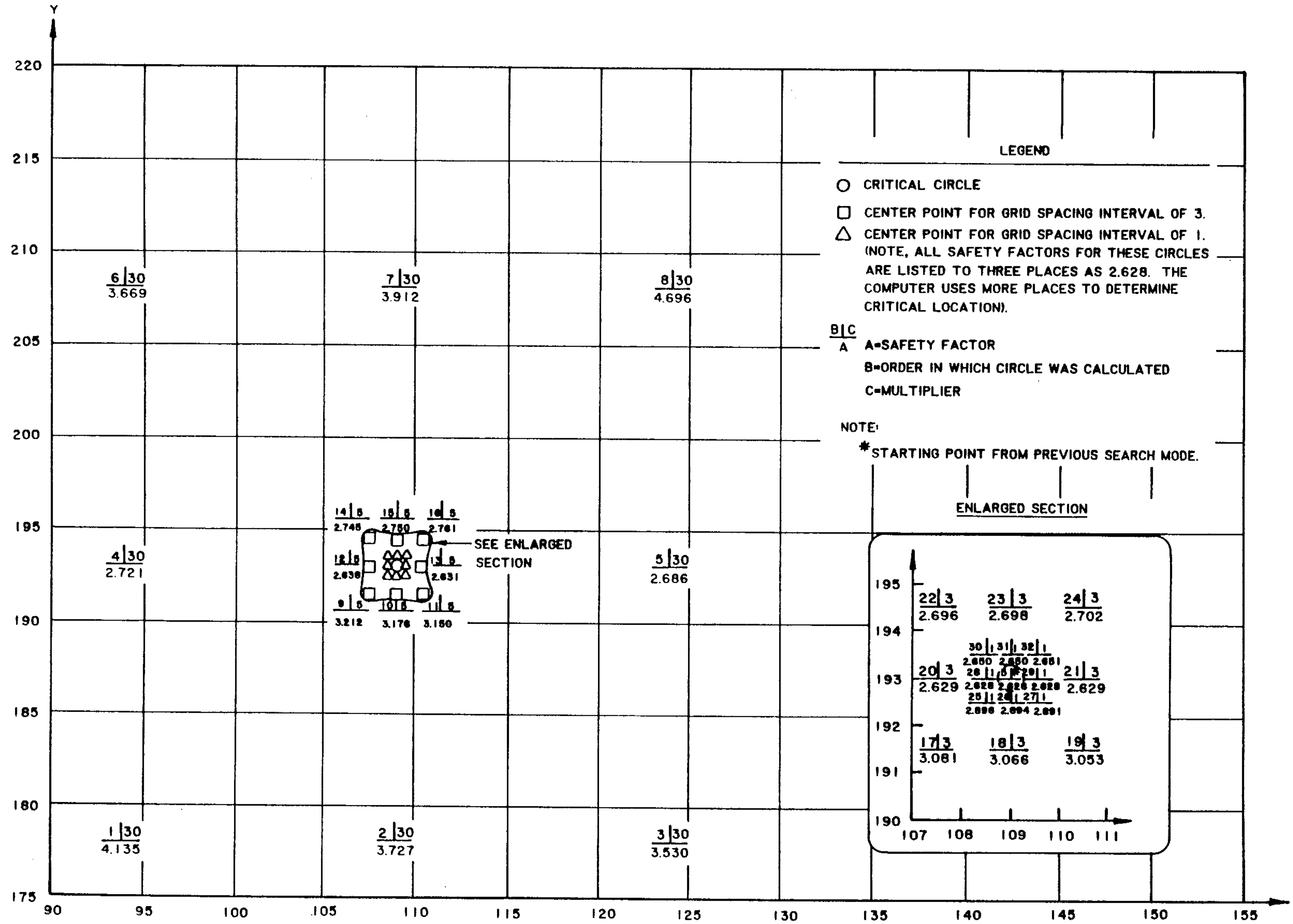
Final Grid Spacing	Initial Search Mode	Minimum Safety Factor	Circle Coordinates X	Circle Coordinates Y	Radius	Total Number of Circles Tried	Total Number of Circles Calculated
5	Tangent 0	2.629	106	185	185	70	58
	Tangent -10	2.723	166	295	300	101	90
	Tangent -20	2.629	111	200	200	118	103
	Point 215,0	2.708	166	360	363.3	119	107
	Radius 180	2.629	106	185	185	103	84
1	Tangent 0	2.628	109	193	193	84	82
	Tangent -10	2.700	170	347	353	335	329
	Tangent -20	2.628	109	193	193	140	137
	Point 215,0	2.700	172	374	378.3	272	270
	Radius 180	2.628	109	193	193	117	114
0.5	Tangent 5	2.628	109	193	193	221	221
	Tangent 0	2.628	109	193	193	92	92
	Tangent -1	2.698	171.5	364	369	819	819
	Tangent -5	2.698	171.5	364	369	170	170
	Tangent -10	2.699	170	349.5	355	379	379
	Tangent -20	2.699	170	349.5	355	425	425
	Point 215,0	2.699	172	365.5	370.8	377	377
	Radius 180	2.628	109	193	193	140	140

* Modified Swedish procedure - Corps side-force inclination of 14°, no tension. Crack initial search point is X = 101 and Y = 180.



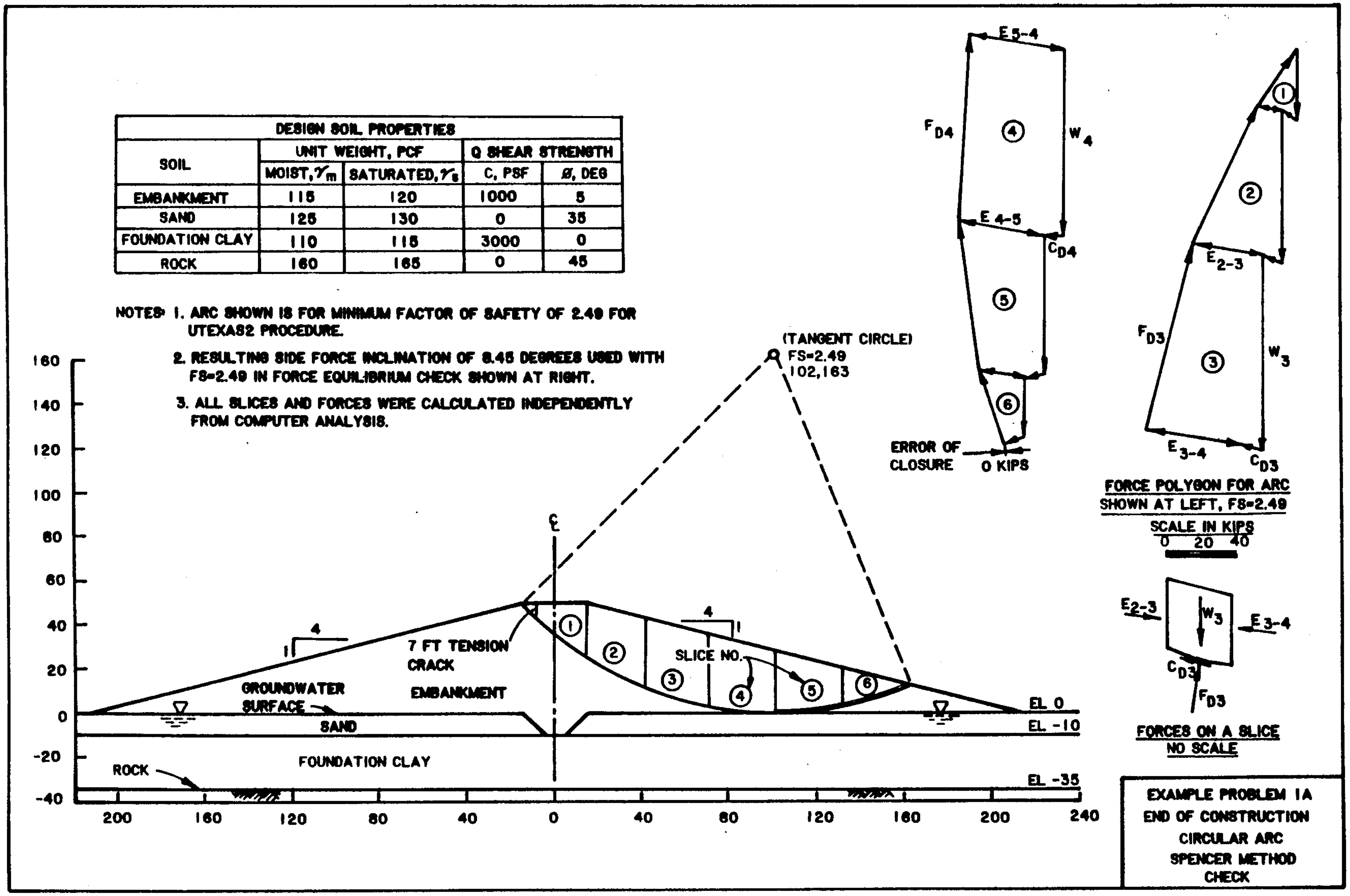
a. Tangent mode

Figure 30. Plots of circle center coordinates for Corps of Engineers Modified Swedish Procedures, EM 1110-2-1902 (Department of the Army 1970) of tangent circle analysis (Continued)



b. Radius search mode

Figure 30. (Concluded)



DESIGN SOIL PROPERTIES				
SOIL	UNIT WEIGHT, PCF		Q SHEAR STRENGTH	
	MOIST, γ_m	SATURATED, γ_s	C, PSF	$\emptyset$, DEG
EMBANKMENT	115	120	1000	5
SAND	125	130	0	35
FOUNDATION CLAY	110	115	3000	0
ROCK	160	165	0	45

Figure 31. Hand check of Spencer's procedure output

shown in Figure 32. Both the spreadsheet results and column definitions are shown in these two figures.

Case 2 - Partial pool case

200. For this case, the (R + S)/2 strength envelope is used for the embankment and foundation clay and the S strength for the sand layer. Figure 33a and 33b illustrates this envelope and shows how the values are determined. The R and S strengths and the appropriate unit weights are listed in Table 25. An example of the cross section representation and profile data was shown in Figure 26. Since part of the embankment is saturated, the embankment should be represented as two materials with the same strength but different unit weights.

201. For this loading case, the phreatic surface is modeled as a straight line from the upstream partial pool level to the center line of the embankment and from there a straight line to the tailwater elevation at the embankment toe. The pore pressure in the sand layer is equal to the pool elevation upstream of the center line and the tailwater elevation downstream of the center line. Since the sand layer is discontinuous, the pore pressure can be represented with one piezometric line which has a sharp change at the center line. The pore pressure for the foundation clay and the rock is modeled the same as the embankment. Figure 34 illustrates the various piezometric lines for a pool elevation of 20 feet.

202. The analysis is performed for several pool elevations with the safety factor plotted as a function of reservoir level to determine the minimum safety factor. For each pool level, a search for the critical circular shear surface is performed. This procedure allows circles with different center points for different pool elevations. Figures 35 through 38 show the tabular and graphic results of the total partial pool analysis for all analysis procedures.

203. When an embankment contains moist and saturated zones, the conservative representation would utilize two materials with the same strength but different unit weights. An alternative to this is to use one material to represent both the moist and saturated portions. The variation in the safety factor is a function of the difference in the weight components. The effect of modeling this example embankment with one or two materials is shown in Table 32 where the results from the 20-foot partial pool case are compared.

SLICE	c' pcf 1	tan phi' 2	b 3	h 4	Gamma * h 5	Alpha deg 6	d*f* sin alph 7	Ru * gam*h 8 (Ru*5)	gam*h - u 9 (5-8)	10 (2*9)	11 (1+10)	12 (3*11)	F. S. 2.49118 13	14 (12/13)
1	1000.00	.0875	13.50	12.80	1472.00	39.60	12666.89	.00	1472.00	128.78	1128.78	15238.58	.7928990	19218.81
2	1000.00	.0875	10.00	21.50	2472.50	34.50	14004.40	.00	2472.50	216.32	1216.32	12163.16	.8440179	14411.01
3	1000.00	.0875	15.00	27.20	3128.00	29.00	22747.28	.00	3128.00	273.66	1273.66	19104.97	.8916458	21426.63
4	1000.00	.0875	15.00	31.00	3565.00	23.30	21151.80	.00	3565.00	311.90	1311.90	19678.46	.9323376	21106.57
5	1000.00	.0875	15.00	32.80	3772.00	17.60	17108.10	.00	3772.00	330.01	1330.01	19950.11	.9638097	20699.22
6	1000.00	.0875	15.00	33.00	3795.00	12.00	11835.38	.00	3795.00	332.02	1332.02	19980.29	.9854493	20275.31
7	1000.00	.0875	15.00	31.80	3657.00	6.60	6304.88	.00	3657.00	319.95	1319.95	19799.19	.9974093	19850.62
8	1000.00	.0875	12.00	29.80	3427.00	2.10	1506.94	.00	3427.00	299.82	1299.82	15597.89	1.000615	15588.29
9	1000.00	.0875	13.00	26.10	3001.50	-2.10	-1429.82	.00	3001.50	262.60	1262.60	16413.77	.9980415	16445.97
10	1000.00	.0875	15.00	21.70	2495.50	-7.40	-4821.14	.00	2495.50	218.33	1218.33	18274.92	.9871479	18512.84
11	1000.00	.0875	15.00	15.20	1748.00	-12.50	-5675.05	.00	1748.00	152.93	1152.93	17293.95	.9686948	17852.84
12	1000.00	.0875	19.00	6.00	690.00	-19.10	-4289.83	.00	690.00	60.37	1060.37	20146.98	.9334572	21583.18

Sum Column 7 91109.82

Sum Column 14 226971.34

$$\text{F. S.} = \frac{\Sigma\,(\text{Column 14})}{\Sigma\,(\text{Column 7})} = 2.4911841$$

Definition of Columns

1 and 2 - material parameters

3 and 4 - slice width and height

5 - overburden pressure at the center of slice base

6 - base inclination of slice

7 - (gamma*h*b) * sin (alpha) or column 5 * column 3 * sin (column 6)

8 - pore pressure head, Ru * (gamma *h)

9 - (gamma*h) - pore pressure or column 5 - column 8

10 - column 2 * column 9

11 - column 1 + column 10

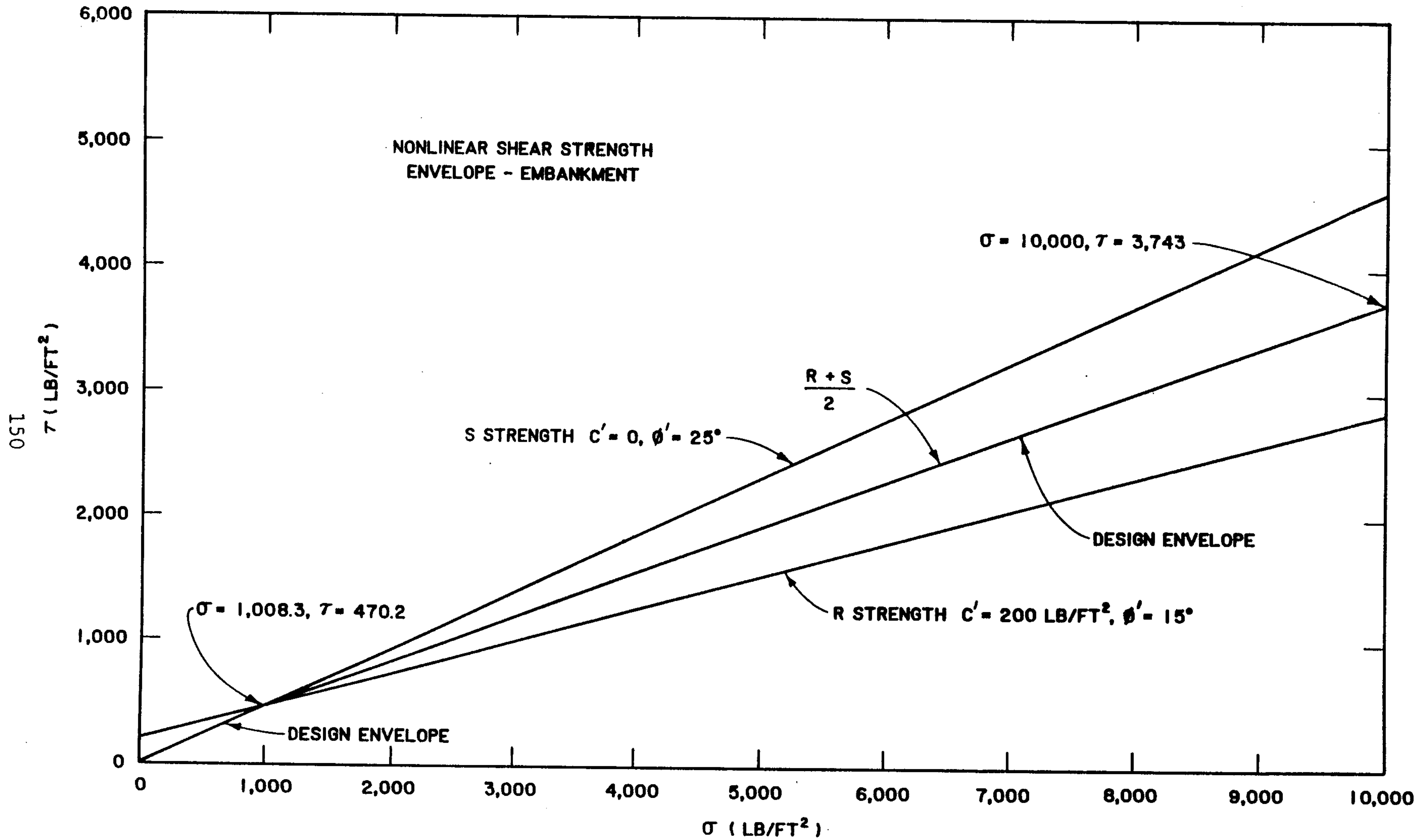
12 - column 3 * column 11

13 - $m\alpha = \cos\alpha\,(1 + \tan\alpha \tan\phi')$ or cos (column 6) $\left(1 + \dfrac{\tan\text{ (col 6) * }\tan\text{ (col 2)}}{\text{F.S.}}\right)$

14 - column 12/$m\alpha$ or column 12/column 13

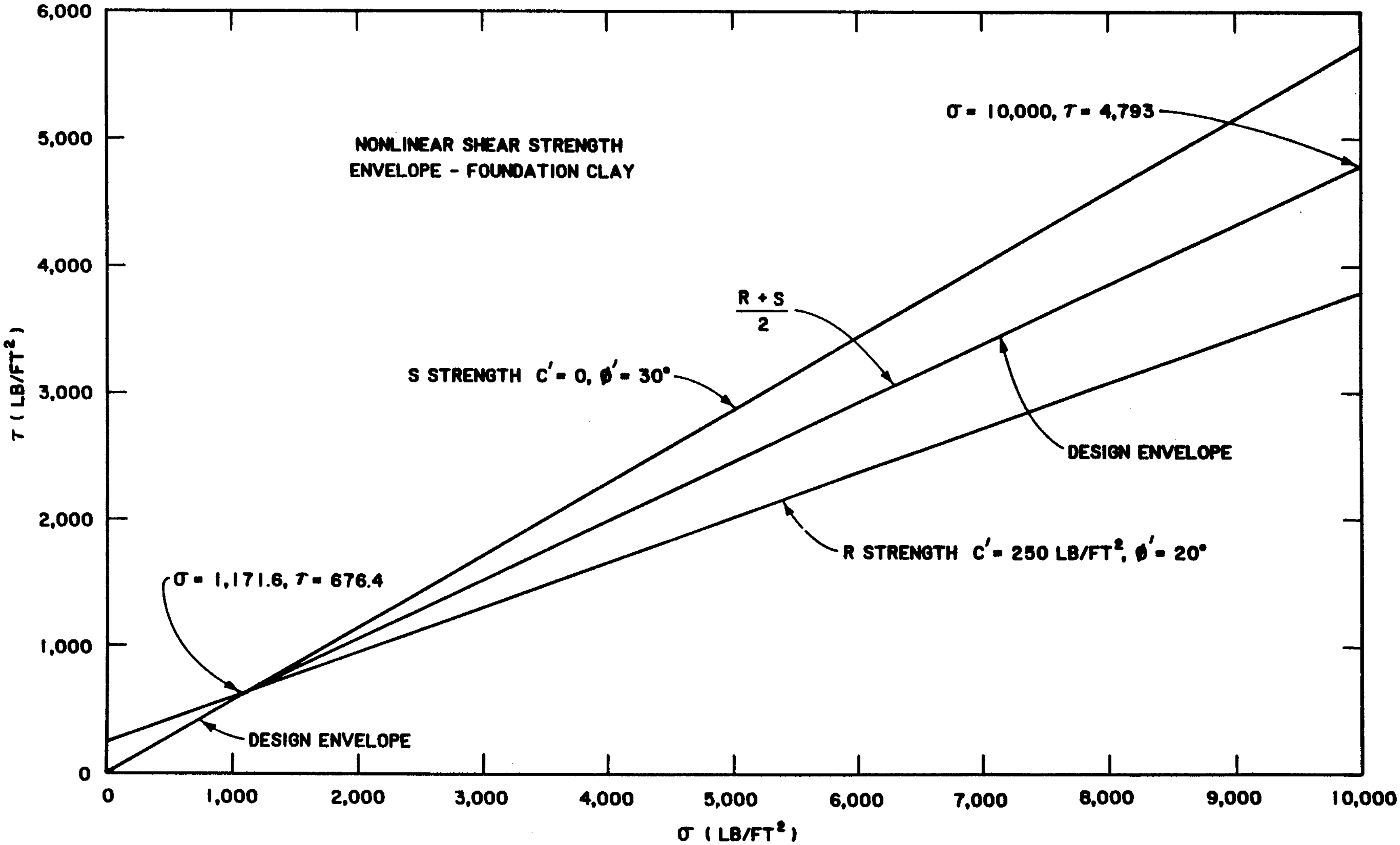
$$\text{F.S.} = \frac{\Sigma\left[b\ (c' + (\gamma h - u)\tan\phi')/m\alpha\right]}{\Sigma\gamma hb\ \sin\alpha}$$

Figure 32. Independent verification by Bishop procedure using a spreadsheet



a. Embankment

Figure 33. Nonlinear shear strength envelope (Continued)



b. Foundation clay

Figure 33. (Concluded)

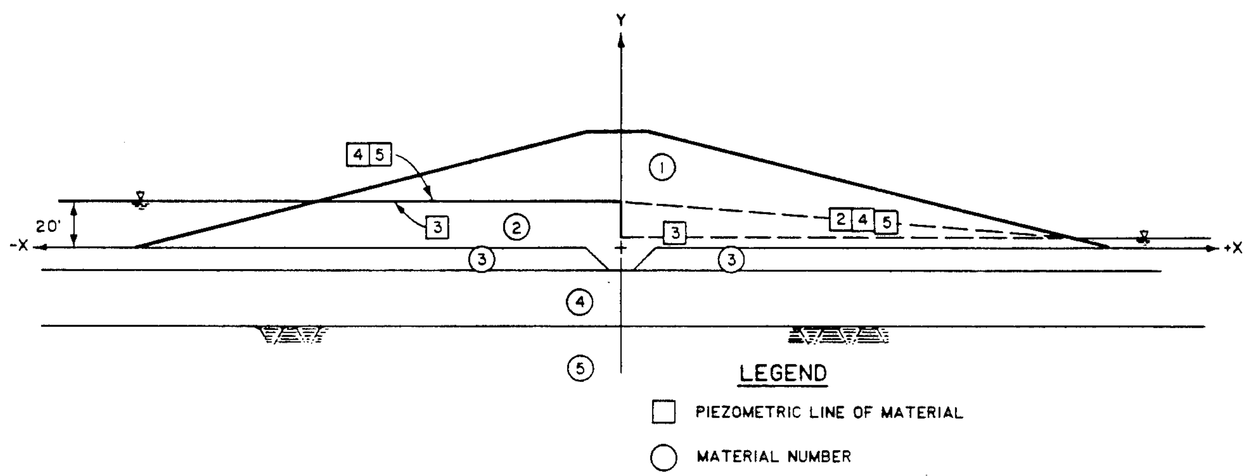
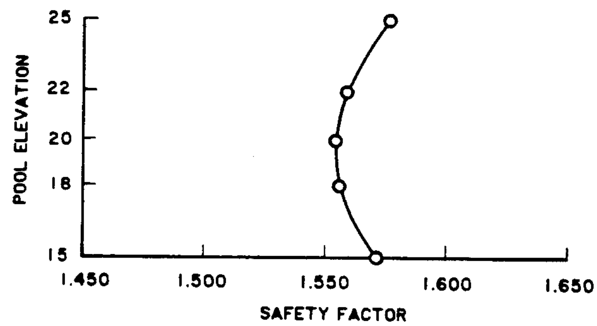


Figure 34. Illustration of various piezometric lines for pool elevation of 20 feet

POOL ELEVATION	MINIMUM SAFETY FACTOR	CIRCLE COORDINATES		RADIUS	SIDE FORCE INCLINATION
		X	Y		
15 FT	- 1.571	-145.0	199.5	199.5	11.62°
18 FT	1.556	-139.0	185.5	185.5	10.79°
20 FT	1.554	-136.0	181.5	181.5	10.23°
22 FT	1.558	-131.5	174.0	174.0	9.77°
25 FT	1.576	-135.5	192.0	192.0	8.79°



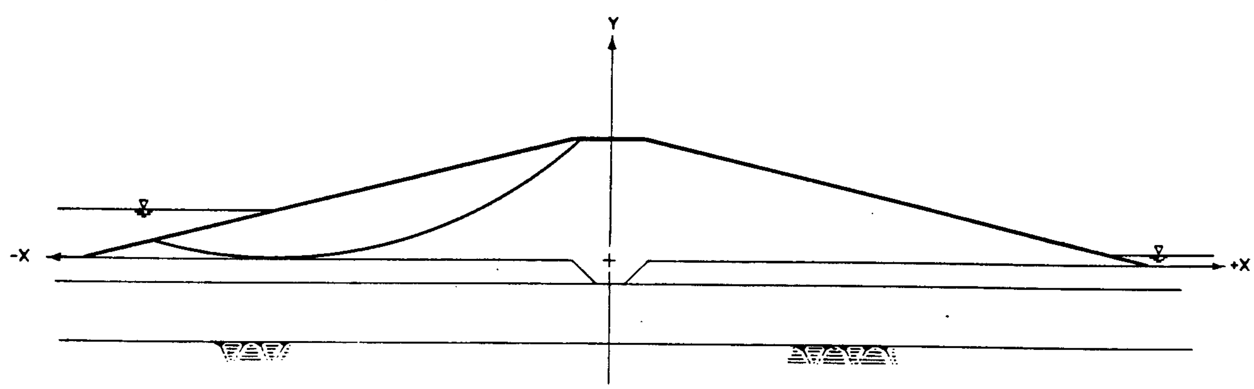
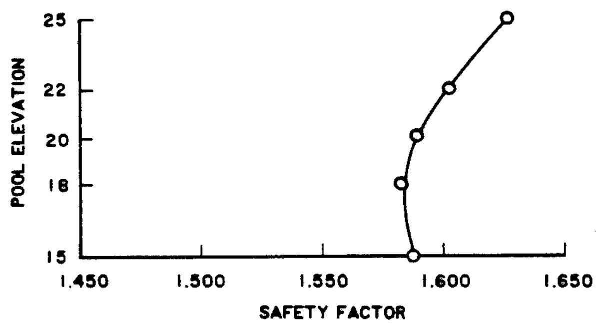


Figure 35. Partial pool analysis for Spencer's procedure (final grid spacing - 0.5, no tension crack)

POOL ELEVATION	MINIMUM SAFETY FACTOR	CIRCLE COORDINATES		RADIUS	SIDE FORCE INCLINATION
		X	Y		
15 FT	1.587	-147.0	206.0	206.0	14.0°
18 FT	1.583	-143.0	198.5	198.5	14.0°
20 FT	1.589	-140.0	195.0	195.0	14.0°
22 FT	1.603	-136.5	194.5	194.5	14.0°
25 FT	1.626	-125.0	182.0	175.5	14.0°



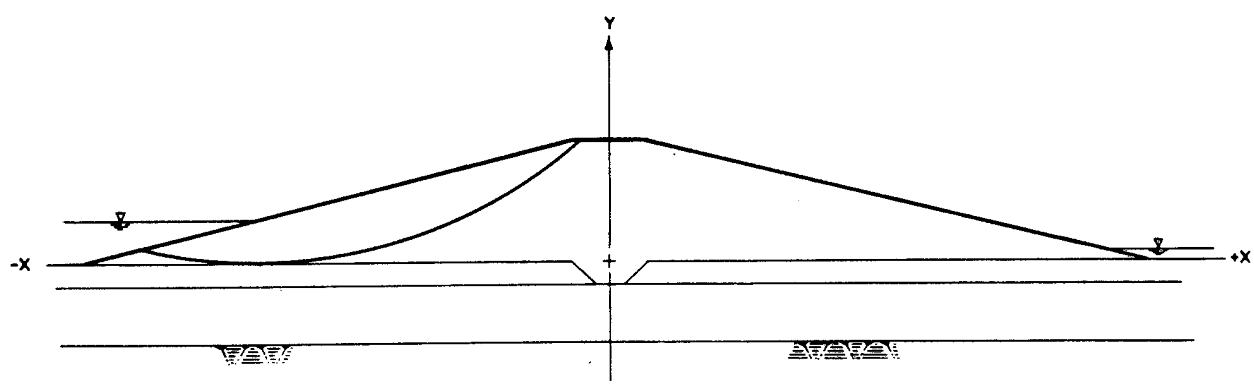
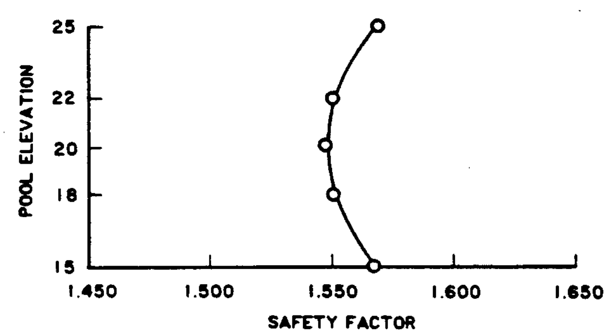


Figure 36. Partial pool analysis for force equilibrium procedure with Corps Modified Swedish side-force inclination (no tension crack)

POOL ELEVATION	MINIMUM SAFETY FACTOR	CIRCLE COORDINATES		RADIUS
		X	Y	
15 FT	1.566	-146.5	201.5	201.5
18 FT	1.550	-138.0	183.5	183.5
20 FT	1.547	-136.0	181.0	181.0
22 FT	1.550	-132.0	174.0	174.0
25 FT	1.568	-135.5	192.0	192.0



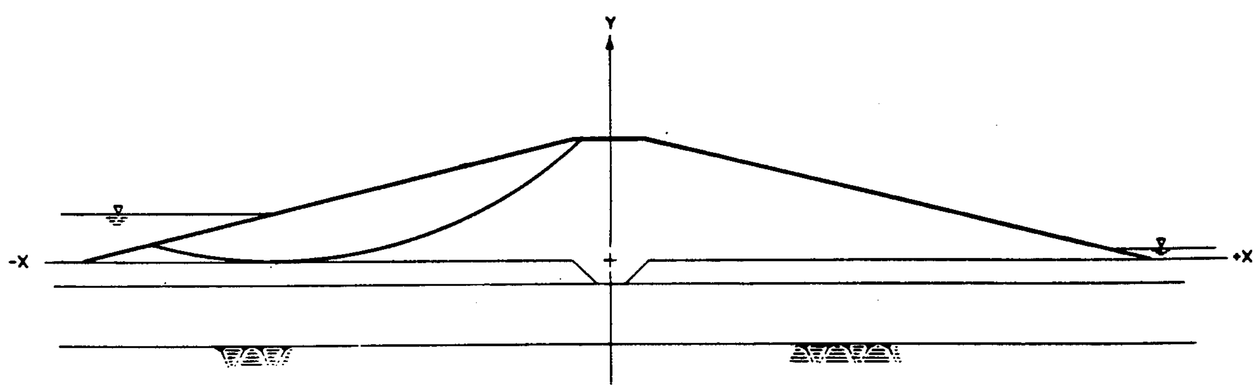
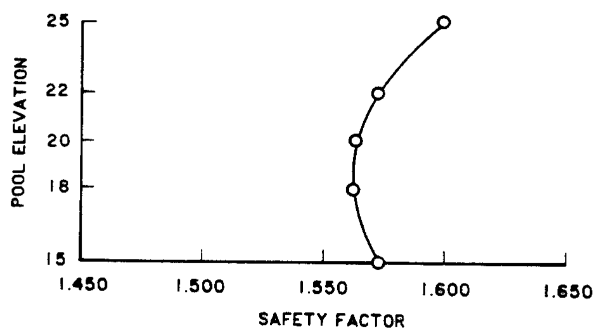


Figure 37. Partial pool analyses for Bishop's procedure (no tension crack, final grid spacing - 0.5 feet)

POOL ELEVATION	MINIMUM SAFETY FACTOR	CIRCLE COORDINATES		RADIUS
		X	Y	
15 FT	1.573	-144.0	196.0	196.0
18 FT	1.562	-137.5	182.5	182.5
20 FT	1.563	-134.0	177.5	177.5
22 FT	1.572	-131.0	174.0	174.0
25 FT	1.599	-133.5	194.0	192.5



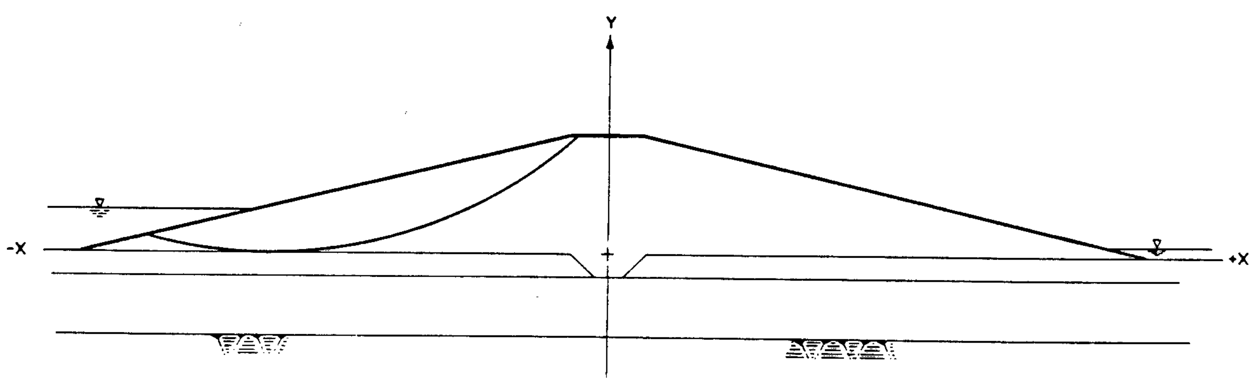


Figure 38. Partial pool analysis for force equilibrium procedure with Lowe and Karafiath's side-force inclination

Table 32

Effects of Modeling Embankment--One Profile With One Unit Weight (No Tension Crack Pool, el 20)

	Analysis Procedure	Min FS*	Critical Circle Data X	Y	R	Side Inclination
Embankment as 2 materials	Spencer	1.554	-136	181.5	181.5	10.23°
	Bishop	1.547	-136	181	181	Horiz
	Corps Modified Swedish	1.589	-140	195	195	14.0°
	Lowe and Karafiath	1.563	-134	177.5	177.5	Varies
Embankment as one saturated material	Spencer	1.530	-134.5	176.5	176.5	10.38°
	Bishop	1.523	-134.5	176.0	176.0	Horiz
	Corps Modified Swedish	1.564	-138.5	190	190	14.0°
	Lowe and Karafiath	1.538	-133	174	174	Varies

* Minimum factor of safety.

Both series of analyses are identical except that the embankment is represented with either one or two materials. The safety factor variation for this example is very small. However, the amount of difference in the safety factors depends on the percentage of the embankment which is moist and saturated, and the difference between the two unit weights.

204. The complete input data file is shown in Figure 39. The computer results are included as file EXAM3B.OUT in Appendix E. The tables and force polygon of a hand check for one pool level are shown in Figure 40.

heading page 21

```
HEADING                                  ← command word
   Example 3 - Circular search
     clay embankment on 10 foot sand layer
     Sand is over 25 foot of clay over rock
PROFILE LINES                            ← command word
 1   1   Embankment surface
  -215    0
    15   50
    15   50
   215    0
                } blank line
 2   2   Upstream sand layer
   400    0
   -15    0
    -5  -10
                } blank line
 3   2   Downstream sand layer
     5  -10
    15    0
   400    0
                } blank line
 4   3   Foundation clay
  -400  -10
   400  -10
                } blank line
 5   4   Rock
  -400  -35
   400  -35
                   } 2 blank lines
HEADING                                  ← command word
  Case 2 - Partial pool
    Phreatic surface in embankment
    Additional piezometric line in sand
MATERIAL PROPERTY                        ← command word
  1  Moist embankment
    115 = moist unit weight
    Nonlinear strength envelope
      -1000        0
          0        0
       1008.3    470.2
      10000     3743.0
                          } blank line
    Piezometric Line
      1     Phreatic surface
  2  Saturated embankment
    120 = saturated unit weight
    Nonlinear strength envelope
      -1000        0
          0        0
       1008.3    470.2
```

profile line data page 22

material property data page 26

Figure 39. Partial-pool data file, for pool level of 20 feet and all analysis procedures (Sheet 1 of 3)

```
                      10000      3743.0
                                         }blank line
                    Piezometric Line
                      1   Phreatic surface
                    3   Sand layer
                     130 = saturated unit weight
                     Conventional shear strength
                      0   35
                     Piezometric Line
                      2
material            4   Foundation clay
property             115 = saturated unit weight
data                 Nonlinear strength envelope
page 26                -1000     0
                           0     0
                        1171.6     676.4
                       10000      4793.2
                                         }blank line
                    Piezometric Line
                      1
                    5   Rock
                     165 = saturated unit weight
                     Conventional shear strength
                      0   45
                     Piezometric Line
                      1
                                         }blank line
                 PIEZOMETRIC LINE DATA  <-------- command word
                    1    62.4    Phreatic surface
                     -400    20
                     -135    20
                        0    20
                      100    12.3
piezometric           195    5
data                  400    5
                                         }blank line
page 41             2            Sand piezometric surface
                      400    20
                        0    20
                        0    5
                      400    5
                                   }2 blank lines
                 SURFACE PRESSURES      pool <-------- command word
surface            -400    0    1248    0
pressure           -215    0    1248    0
data               -135   20       0    0
page 54             195    5       0    0
                    215    0     312    0
                    400    0     312    0
                                         }blank line
                 HEADING            <------------- command word
heading             Search for critical circle - pool level = 20 ft
page 21             Spencer's analysis procedure
                    Tangent search mode - elev. 0
                 PLOT               <------------- command word
```

Figure 39. (Sheet 2 of 3)

analysis/ computation data page 69

```
ANALYSIS/COMPUTATION  ◄— command word
  Circular Search
   -150  170  0.5  -50
   Tangent
    0
   SHORT
   PROCEDURE
    Spencer
                {blank line
```

heading page 21

```
COMPUTE               ◄——— command word
HEADING               ◄——— command word
  Search for critical circle - pool level = 20 ft
  Corps Modified Swedish analysis procedure
  Tangent search mode - elev. 0
```

analysis/ computation data page 69

```
ANALYSIS/COMPUTATION  ◄— command word
  Circular Search
   -175  240  0.5  -50
   Tangent
    0
   PROCEDURE
    Corps
     14.0
                {blank line
```

heading page 21

```
COMPUTE               ◄——— command word
HEADING               ◄——— command word
  Search for critical circle - pool level = 20 ft
  Bishop's analysis procedure
  Tangent search mode - elev. 0
```

analysis/ computation data page 69

```
ANALYSIS/COMPUTATION  ◄— command word
  Circular Search
   -140  170  0.5  -50
   Tangent
    0
   PROCEDURE
    Bishop
                {blank line
```

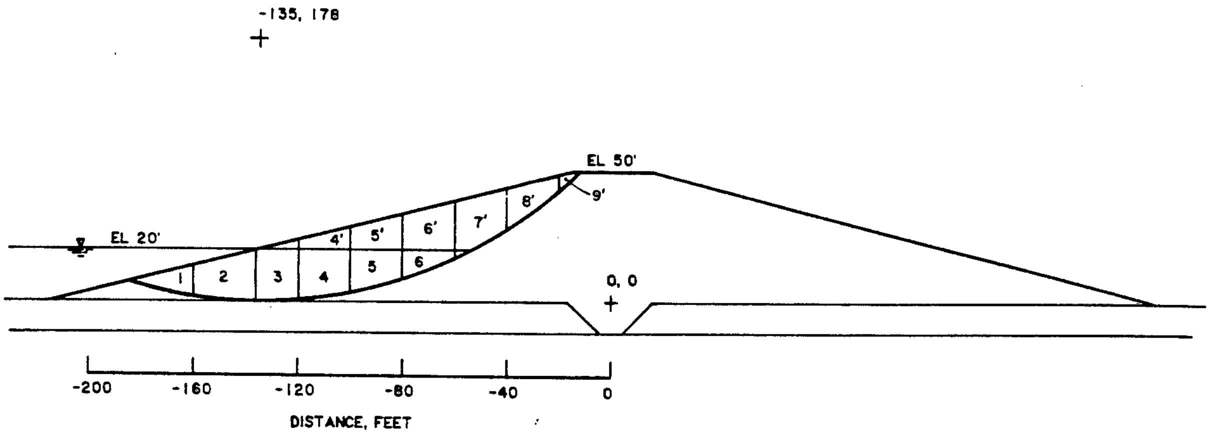
heading page 21

```
COMPUTE               ◄——— command word
HEADING               ◄——— command word
  Search for critical circle - pool level = 20 ft
  Lowe and Karafiath's analysis procedure
  Tangent search mode - elev. 0
```

analysis/ computation data page 69

```
ANALYSIS/COMPUTATION  ◄— command word
  Circular Search
   -160  230  0.5  -50
   Tangent
    0
   PROCEDURE
    Lowe
                {blank line
COMPUTE               ◄——— command word
```

Figure 39. (Sheet 3 of 3)



Slice No.	Slice Geometry: Slice Width, b	Slice Height: Left	Slice Height: Right
1	24	0	11
2	24	11	20
3	16	20	19
3'	16	0	4
4	20	19	16
4'	20	4	9
5	20	16	11
5'	20	9	14
6	20	11	3
6'	20	14	19
7	20	3	0
7'	20	19	16
8	20	16	7
9	8	7	0

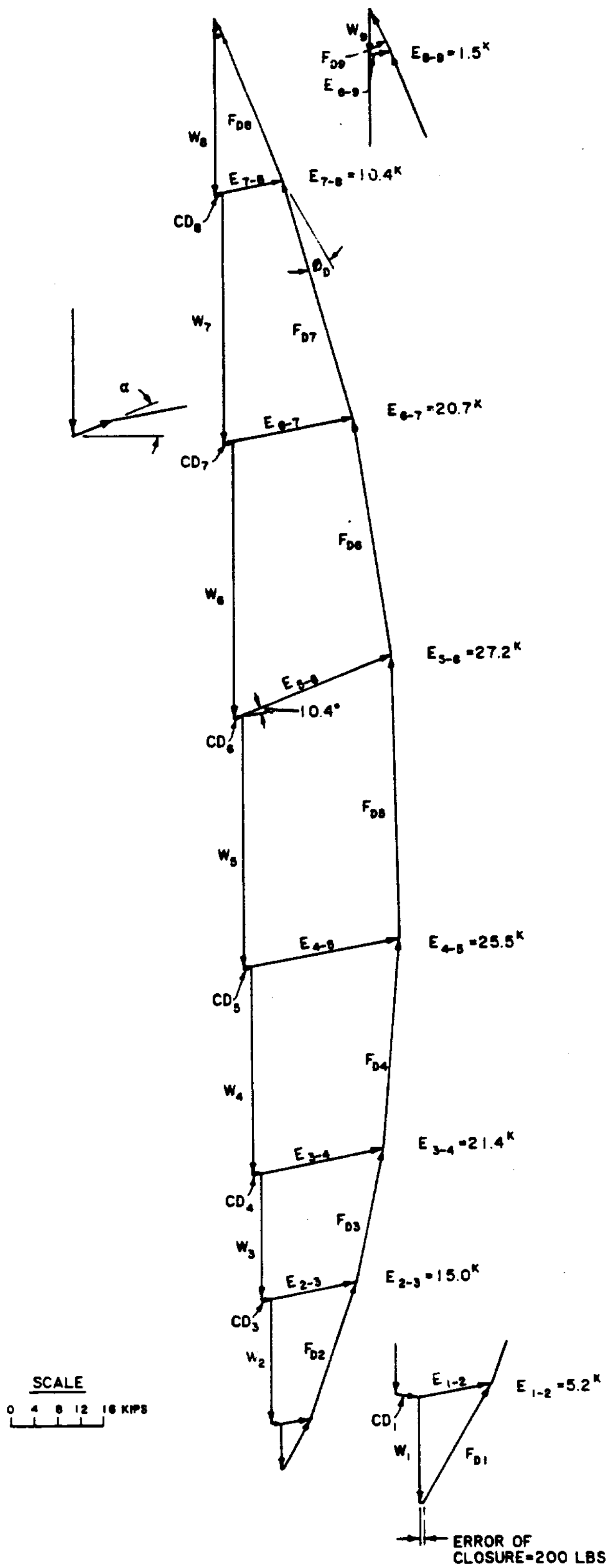
Material Properties

Soil	Tan ϕ: R	Tan ϕ: S	Tan ϕ: $\frac{R+S}{2}$	Cohesion: R	Cohesion: S	Cohesion: $\frac{R+S}{2}$	Unit WT: γ_s	Unit WT: γ_{sub}
Embankment	.268	.466	.367	200	0	100	120	57.6
FNDN Sand	.700	.700	.700	0	0	0	130	67.6
FNDN Clay	.364	.577	.471	250	0	125	115	52.6

Developed Strengths for Trail FS = 1.53

Soil	Tan ϕ_D: S	Tan ϕ_D: $\frac{R+S}{2}$	ϕ_D: S	ϕ_D: $\frac{R+S}{2}$	Cohesion: S	Cohesion: $\frac{R+S}{2}$
Embankment	.305	.240	17.0	13.5	0	65.4

Figure 40. Hand check for Example 3, partial pool using force equilibrium procedure with Corps Modified Swedish side-force inclination (Continued)



Force Polygon Data

Slice No.	Slice Weight, w(kips)	ΔL	α	C_D	CD(k/ft)
1	7.6	25	-12.5°	0.0	0.0
2	21.4	25	-5.0°	65.4	1.6
3	21.8	17	2.0°	65.4	1.1
4	35.8	21	9.0°	65.4	1.4
5	43.2	21	14.5°	65.4	1.4
6	47.7	22	22.0°	65.4	1.4
7	43.7	23	29.0°	65.4	1.5
8	27.6	25	35.0°	65.4	1.6
9	3.4	12	41.0°	0.0	0.0

Notes:

Slices 1 and 9 use ϕ_D S-STR

Slices 2 thru 8 use ϕ_D R+S/2 STR

ΔL = length of slice base, b/cos α

Assume constant angle of side force inclination = 10.4°

Figure 40. (Concluded)

Example 4: Cut Slope - Noncircular Search

205. Stability computations for the undrained condition are performed for this example problem. Both circular and noncircular shear surfaces are considered. Searches for the critical location of both types of shear surfaces are presented. Spencer's analysis procedure will be used for both the circular searches and the noncircular searches. Details concerning the effects of stratification, initial shift distance, and the number and location of points used to define the shear surface are provided for the noncircular search. A method to evaluate the variation of the base width is presented.

Slope description

206. This example slope, shown in Figure 41, consists of a total of five sand and clay layers. The top two layers are clay over a sand layer with the sand divided by a thin layer of fat clay. The example models a channel because the slope is symmetrical about the center line which is the zero point of the x axis. A cross section of the left side of the cut slope is shown in Figure 41. The steep portion of the slope is 40 feet tall with 1 (vertical) to 3 (horizontal) slopes for the lower half of the cut below a 10-feet wide bench. The upper half of the cut has a slope of 1 to 2. The coordinate axes are the channel center line X and the top of rock Y. The groundwater table is at the top of the upper sand layer until near the cut where it lowers to the bottom of the upper sand layer at the point it emerges from the slope. There is 5 feet of water in the channel. Table 33 lists the various unit weights and shear strength values for the materials in this problem.

207. The geometry for this problem can be represented in two ways. The profile lines can describe the horizontal and slope portions of each profile. However, this representation does not allow the user to easily change the slope angle. The other method of modeling this geometry is to have the profile lines describe only the horizontal boundaries. The top layer would be a horizontal line at el 80. The cut slope is modeled with slope geometry data which describes just the slope profile. This method of representation allows the user to easily vary the slopes and evaluate the results. This latter method of describing the cross section is shown in Figure 42. The groundwater table is modeled as a piezometric line. The portion of the data file up to the ANALYSIS/COMPUTATION data is shown in Figure 43.

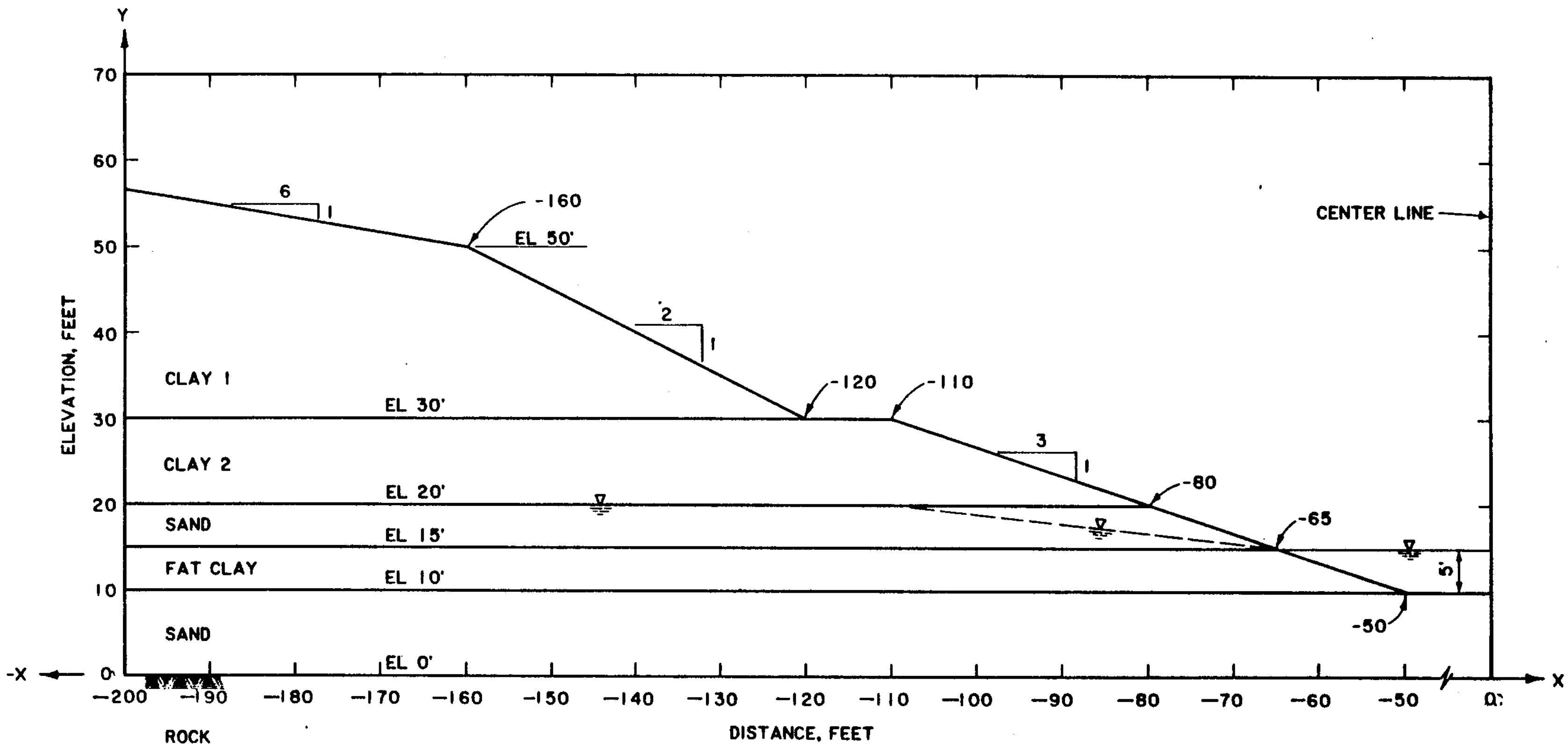


Figure 41. Example 4 - cross section

Table 33

Soil Properties for Example 4

	γ_s, pcf	γ_m, pcf	C , psf	ϕ°
Clay 1	120	115	1,500	5
Clay 2	120	115	1,000	0
Sand	125	120	0	30
Fat Clay	120	115	500	0
Rock	165	165	0	45

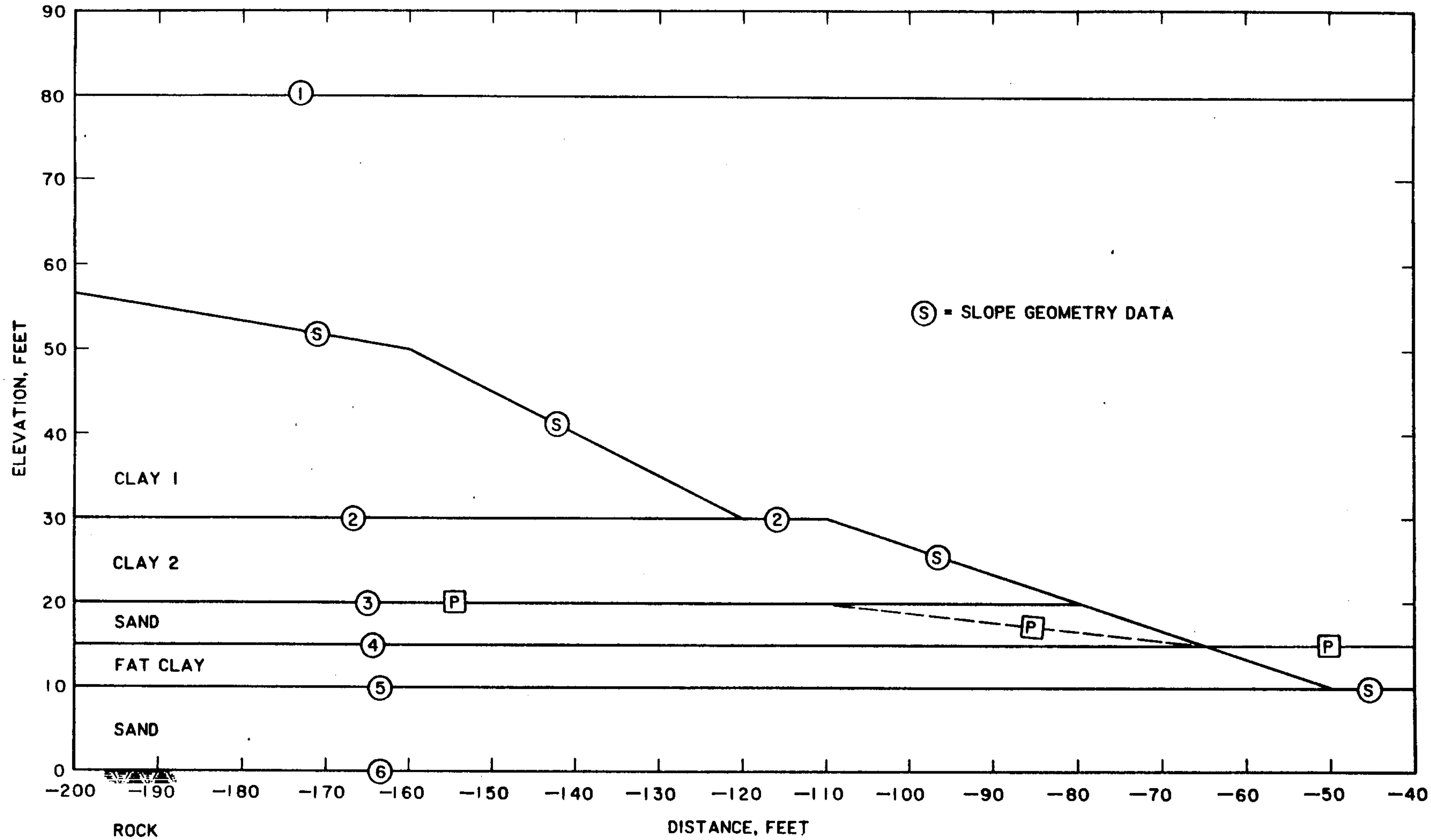


Figure 42. Profile data representation for Example 4

```
heading      HEADING  <-----  command word
page 21        Example 4 - Noncircular search
                 Natural slope or cut slope problem
                 Contains five layers over rock
             PROFILE LINES  <-----  command word
               1    1    Clay 1
              -340   80
               340   80
                               } blank line
               2    2    Clay 2
              -340   30
               340   30
                               } blank line
               3    3    Upper sand
              -340   20
profile        340   20
line                           } blank line
data           4    4    Fat clay
page 22       -340   15
               340   15
                               } blank line
               5    5    Lower sand
              -340   10
               340   10
                               } blank line
               6    6    Rock
              -340   0
               340   0
                               } 2 blank lines
             HEADING  <-----  command word
heading        Undrained strengths
page 21        Water table in upper sand layer
                                              } blank line
             MATERIAL PROPERTY  <-----  command word
               1   Clay 1
                115 = moist unit weight
                Conventional shear strength
                 1500     5
                NO  pore pressure
               2   Clay 2
                115 = moist unit weight
                Conventional shear strength
                 1000     0
material        NO  pore pressure
property       3   Upper sand layer
data            125 = saturated unit weight
page 26         Conventional shear strength
                 0    30
                Piezometric Line
                 1
               4   Fat clay
                120 = saturated unit weight
                Conventional shear strength
```

Figure 43. Initial portion of cut slope example data profile (Continued)

material property data page 26

```
 500   0
Piezometric Line
 1
5  Lower sand layer
 125 = saturated unit weight
Conventional shear strength
 0   30
Piezometric Line
 1
6  Rock
 165 = saturated unit weight
Conventional shear strength
 0   45
Piezometric Line
 1
```

blank line

piezometric data page 41

```
PIEZOMETRIC LINE DATA
  1     62.4   Water table
  -340    20
  -110    20
   -65    15
    65    15
   110    20
   340    20
```

command word

2 blank lines

surface pressure data page 54

```
SURFACE PRESSURE
  -65   15     0   0
  -50   10   312   0
   50   10   312   0
   65   15     0   0
```

command word

blank line

slope geometry data page 51

```
SLOPE GEOMETRY
  -340   80
  -160   50
  -120   30
  -110   30
   -50   10
    50   10
   110   30
   120   30
   160   50
   340   80
```

command word

blank line

Figure 43. (Concluded)

Circular shear surface

208. Searches for the critical circular shear surface were performed using Spencer's procedure. The first of three series of analyses was initiated from the same point (X = -120 and Y = 110) with a final grid spacing of 0.4 feet. All searches began in the tangent mode at different elevations, and tension cracks were used. The depth of tension cracks varied from 5 to 20 feet for shallow to deeper circles. Once a search is begun, the depth of the tension crack is held constant. Table 34 lists the results of this analysis. The four local minimums found in this analysis are shown in Figure 44. A second series of analyses varied the initiation point of the search. The results of these analyses are summarized in Table 35. These analyses illustrate that the first series of analyses found the true minimum and not just a local minimum.

Noncircular shear surface

209. All the data prior to the ANALYSIS/COMPUTATION data are the same for noncircular shear surfaces as for circular shear surfaces. The shear surface and associated data is specified in the ANALYSIS/COMPUTATION data group. For a single shear surface analysis, only the X and Y coordinates of the surface are necessary. For noncircular searches, the X and Y coordinates of the initial surface are required. In addition, the direction of movement of each point in the shear surface can be specified. The user specifies one of three options describing the movement. The point is either completely movable, non-movable (fixed), or movable in a particular direction. This direction of movement is specified by an angle in degrees from the horizontal with counterclockwise being positive. After all the surface points are entered, an initial shift distance and maximum steepness of the toe portion are input. Usually the default value of 50 degrees is used for the maximum steepness angle in which case no input is required. The initial shift distance is the initial increment that the shear surface points are moved. During the search, the shift distance is reduced to 70 percent, 40 percent, and finally 10 percent of the initial value. Tension cracks are specified by starting or ending the shear surface at the bottom of the crack. For noncircular surfaces, the crack depth option is not utilized. The tension crack will be the same depth for all analyses. Both end points of the shear surface are moved parallel to the outer slope unless they are fixed. An initial

Table 34

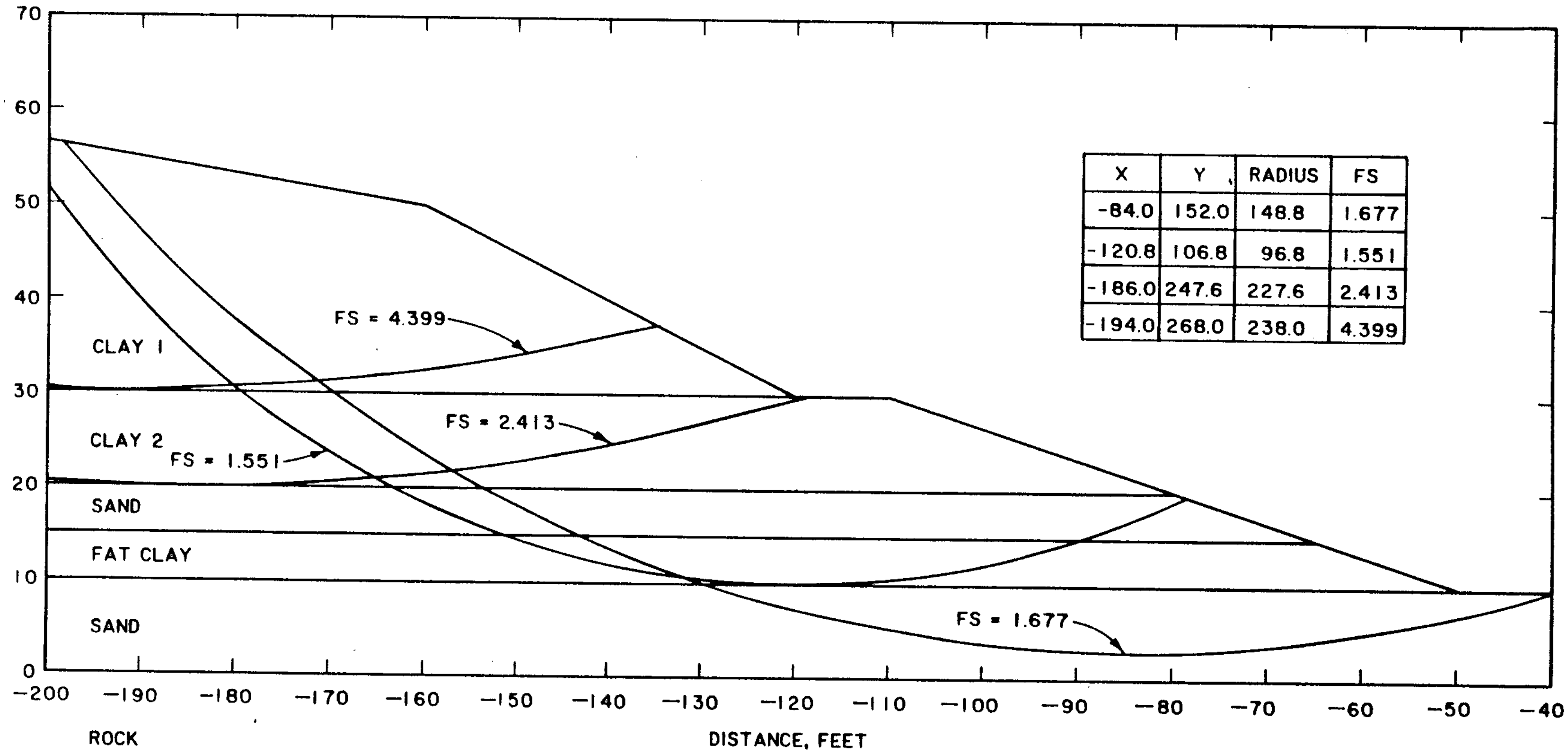
Circular Searches Using Spencer's Procedure and Varying Tangent Elevation

(Starting Point for Search X = -120 , Y = 110

Final Grid Spacing = 0.4)

Tangent Elevation of Initial Search, ft	Minimum FS*	Circle Coordinates X, ft	Circle Coordinates Y, ft	Circle Coordinates Radius, ft	Side-Force Inclination, deg	Tension Crack Depth, ft
-5	1.677	-83.6	153.2	150.6	-11.22	20
0	1.677	-84.0	152.0	148.8	-11.27	20
5	1.677	-83.8	154.2	150.8	-11.27	20
10	1.551	-120.8	106.8	96.8	-7.63	20
15	1.677	-83.6	155.2	152.2	-11.20	20
20	2.413	-186.0	247.6	227.6	-7.15	10
25	1.570	-120.0	104.0	93.8	-7.70	15
30	4.399	-194.0	268.0	238.0	-7.98	5

* Minimum factor of safety.



X	Y	RADIUS	FS
-84.0	152.0	148.8	1.677
-120.8	106.8	96.8	1.551
-186.0	247.6	227.6	2.413
-194.0	268.0	238.0	4.399

Figure 44. Final circular shear surfaces for different initial tangent elevations

Table 35

Summary of Search Analyses for Critical Circular Shear Surface

Using Spencer's Procedure

Initial Circle Data				Final Circle Data				
X	Y	Tangent Elevation ft	Minimum FS*	X, ft	Y, ft	Radius ft	Side-Force Inclination deg	Tension Crack Depth ft
-120	110	10	1.551	-120.8	106.8	96.8	-7.63	20
-90	100	10	1.551	-120.8	106.8	96.8	-7.63	20
-160	150	10	1.551	-120.8	106.8	96.8	-7.63	20
-120	110	0	1.677	-84.0	152.0	148.8	-11.27	20
-80	140	0	1.677	-84.0	152.0	148.8	-11.27	20
-160	90	0	1.677	-84.0	152.0	148.8	-11.27	20
-120	110	20	2.413	-186.0	247.6	227.6	-7.15	10
-95	85	20	2.412	-186.2	247.0	227.0	-7.15	10
-140	140	20	2.413	-186.0	247.6	227.6	-7.15	10
-120	110	30	4.399	-194.0	268.0	238.0	-7.98	5
-130	80	30	1.671	-124.8	116.0	106.0	-0.98	5
-140	130	30	4.369	-188.0	286.0	256.0	-8.20	5
-90	140	30	4.369	-188.0	286.0	256.0	-8.20	5

* Minimum factor of safety.

estimate of a noncircular shear surface, developed from the results of the circular analysis, and the input data necessary for a search are shown in Figure 45.

210. A series of noncircular search procedure will generate surfaces that are not identical; however, safety factors are within about a 5 percent range. The series of analyses described with this example will illustrate several important points of which the user should be aware and/or evaluate.

211. The first series of analyses will illustrate the movement of the initial shear surface and the effect of the shift distance. For these analyses, the elevation of the flat portion of the shear surface was varied with the initial positions shown in Figure 46. All surfaces are defined by six points with the initial shift distance set to 10 feet. This value was selected so that the final surfaces would be within a 1-foot band. The smallest layer is 5 feet thick, and a resolution of 20 percent is necessary to obtain the 1-foot band. Since this 1-foot band is to be 10 percent of the initial shift distance, the input for the initial distance is 10 feet. A tension crack of 20 feet was used for all cases except for surface 5 where a 15-foot crack was used. Table 36 lists both the initial and final shear surfaces from the analyses. The 1-foot band location of the final surfaces is shown in Figure 46. For this example, all surfaces moved to the lower foot of the fat clay layer. However, the user should select the most appropriate surface for any given problem since this movement may not occur if there is a large variation in the strata thickness.

212. To evaluate the initial shift distance, it was varied from 2 to 20 feet for surfaces 1 and 2. Also, for the other surfaces listed in Table 36, the shift distance was changed to 10 feet. Table 37 summarizes the safety factors for all the various surfaces. Only relatively small changes in the safety factor occurred for changes in the shift distance. By decreasing the shift distance, the band for the final shear surface decreases along with the area searched. For some of the larger shift distances, errors occurred when the second point from the toe was shifted outside the slope. A number of analyses had negative stresses, indicating that a deeper tension crack was necessary. However, for illustrative purposes, the initial surface shown in Table 36 was not changed. In general, the safety factors tend to decrease as the shift distance decreases. However, for this example problem, a shift

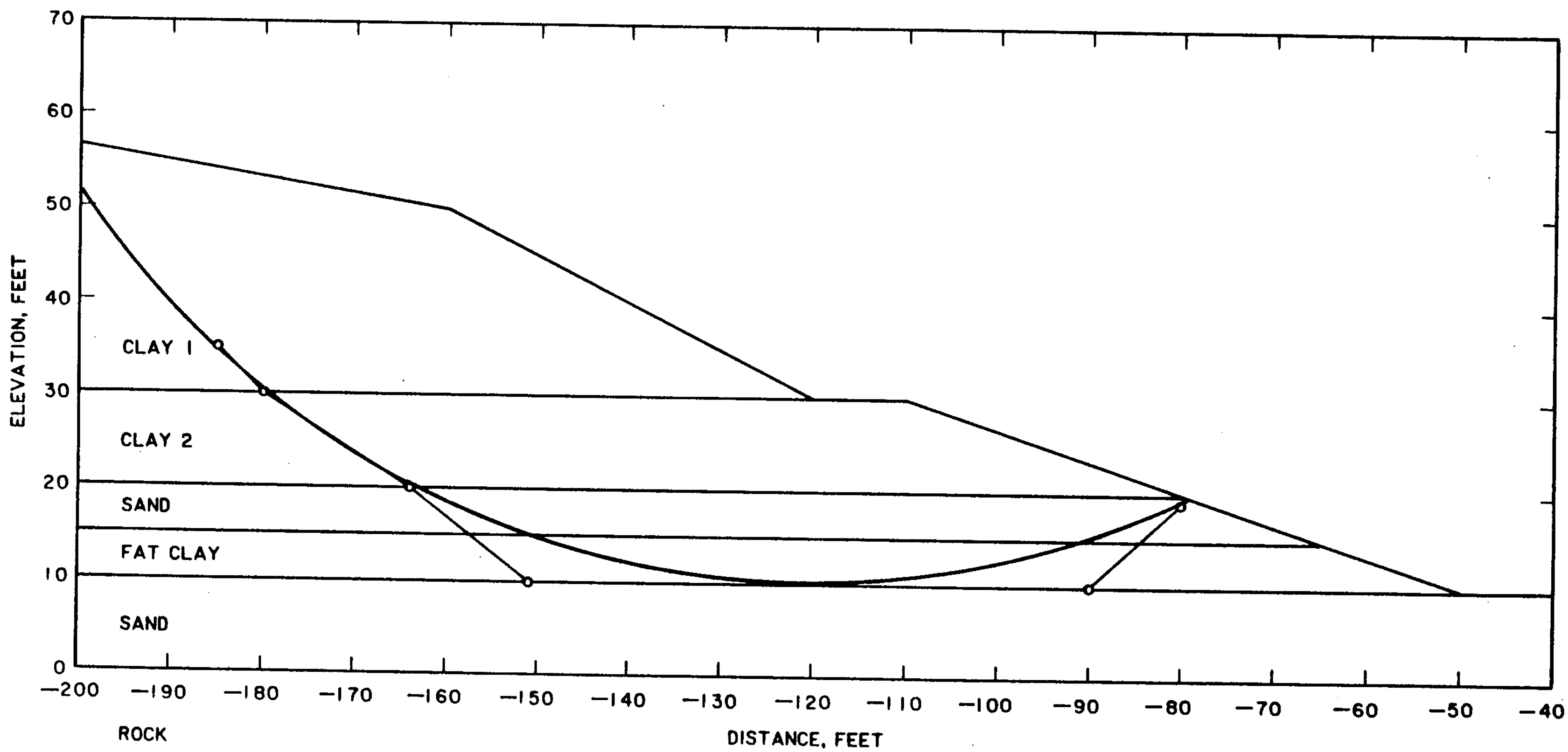


Figure 45. Initial noncircular shear surface

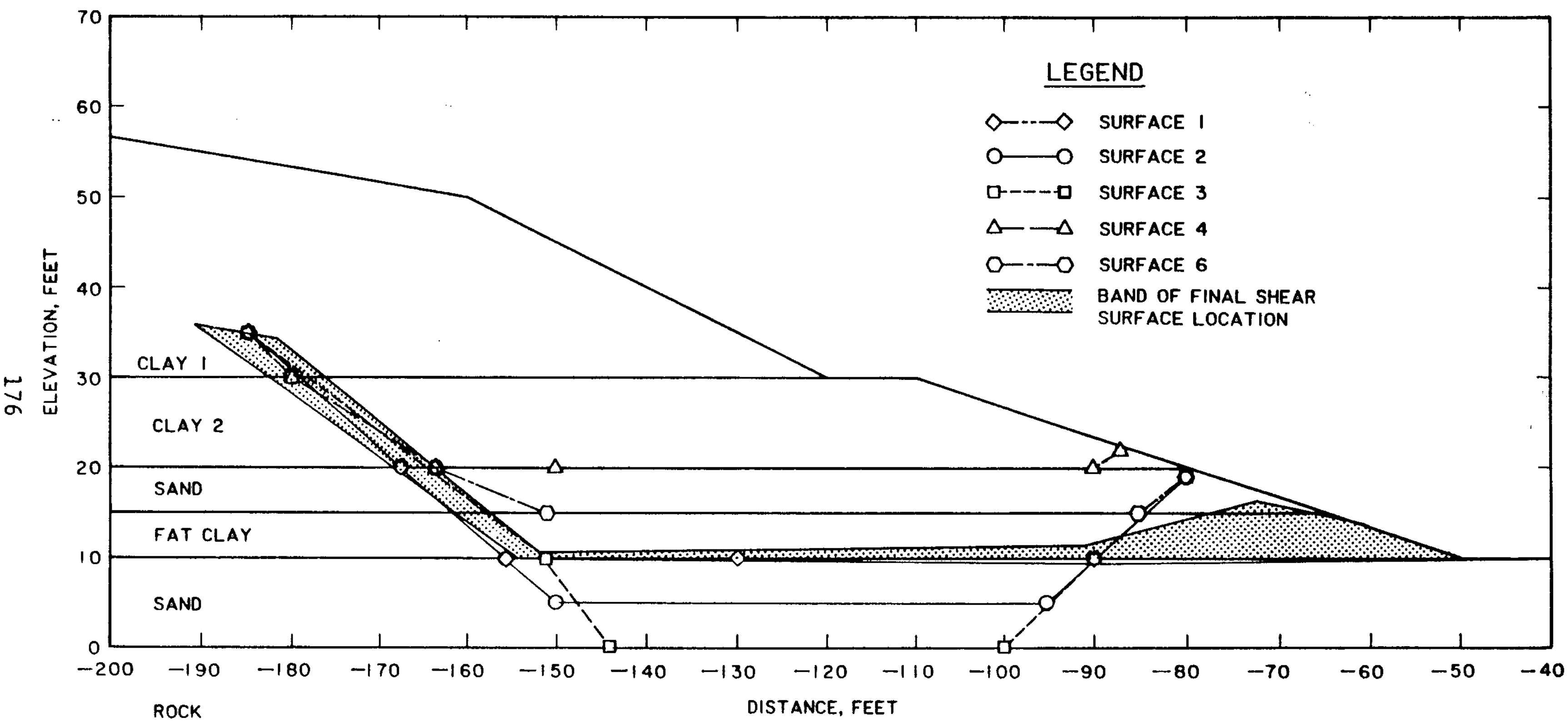


Figure 46. Initial noncircular shear surface and final location band illustrating the shear surface movement during the search process

Table 36

Variation of Base Elevation; Initial Shift Distance = 10 feet

Surface 1, FS* = 1.371				Surface 2, FS = 1.330				Surface 3 FS = 1.332			
Initial		Final		Initial		Final		Initial		Final	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
-185	35	-188.0	35.0	-185	35	-190.7	36.0	-185	35	-182.0	34.5
-167.5	20	-168.0	20.3	-167.5	20	-171.4	14.7	-151	10	-156.4	11.7
-155.5	10	-154.6	10.1	-155.5	10	-155.4	11.2	-144	0	-135.8	10.8
-130	10	-130.0	10.4	-150	5	-145.4	10.1	-100	0	-104.2	11.0
-90	10	-91.3	11.4	-95	5	-99.2	10.9	-90	10	-89.2	9.3
-80	19	-72.2	16.4	-80	19	-72.3	16.4	-80	19	-42.4	10.0

Surface 4 FS = 1.397				Surface 5** FS = 1.346			
Initial		Final		Initial		Final	
X	Y	X	Y	X	Y	X	Y
-185	35	-185.3	35.0	-190	41	-194.4	41.7
-180	30	-180.2	30.5	-180	30	-181.2	28.1
-164	20	-165.3	20.4	-164	20	-167.6	14.7
-150	20	-149.4	11.0	-150	20	-149.9	10.0
-90	20	-89.1	10.0	-90	20	-89.1	10.4
-87	22	-70.9	16.6	-87	22	-70.9	16.6

Surface 6 FS = 1.371				Surface 7† FS = 1.347			
Initial		Final		Initial		Final	
X	Y	X	Y	X	Y	X	Y
-185	35	-182.7	34.6	-185	35	-181.4	34.4
-180	30	-179.5	30.5	-180	30	-178.7	31.1
-164	20	-163.5	20.9	-164	20	-163.6	20.4
-151	15	-151.9	10.5	-151	14.5	-152.2	10.0
-85	15	-84.7	10.0	-85	15.5	-84.1	10.0
-80	19	-69.0	15.3	-80	19	-70.8	15.9

* Factor of safety.
** 15-ft tension crack.
† Attempted crossover.

Table 37

Effect of Initial Shift Distance

Surface*	Initial Shift Distance, ft	Safety Factor
1	20	1.555
	15	1.393
	10	1.371
	5	1.305
	2	1.348
2	20	--
	15	1.341
	10	1.330
	5	1.313
	2	1.304
3	10	1.332
	5	1.315
4	10	1.397
	5	1.314
5	10	1.346
	5	1.357
6	10	1.371
	5	1.368
7	10	1.347
	5	1.360

* Initial surfaces are defined in Table 34.

distance of 10 feet will be used for the other analyses because a resolution or band width of 1-foot is sufficient.

213. The second series of analyses evaluated the effect of the number of points used to define the shear surface. An initial shear surface defined by 13 points was used in a search for the final surface. Using the same initial points, subgroups of 4, 6, 7, 8, 9, 11, and 13 points were used in searches for the final surface. All points were movable during the search, with an initial shift distance of 10 feet. Table 38 lists the initial points that were used in the various subgroups, and the final results. The initial and selected final surfaces are shown in Figure 47. For the surfaces with 6 to 13 points, the safety factor was about constant with a minimum occurring for the nine-point surface. The surface using four points generated a safety factor about 4 percent larger than the other surfaces.

214. In addition to the number of points defining a shear surface, the distribution of the points along the surface was also evaluated. Two cases were analyzed for the six-point surface. In the first case, four points were located along the base. For the second case, four points were used to define the intersection of different materials along the active portion of the surface. For both cases, the movement of the points was not restricted. There is a 5 percent difference in the final safety factors. This indicates that when a few points are used to define the surface, more points should be located along the base than are used to define the active portion of the surface. Figure 48 compares the active portion of the final surface for both six-point shear surfaces.

215. The two seven-point surfaces listed in Table 38 were used to illustrate analyses where the movement of the points was limited. For both seven-point surfaces, points are located at every soil layer intersection. The first seven-point surface allowed the points to move in any direction. The second analysis restricted the points to movement only along the soil layers. For the second analysis (surface J in Table 38), it should be noted that the final surface does not contain a central block. The search resulted in a surface consisting only of an active and a passive wedge. Both final active wedge surfaces are included in Figure 48. There is approximately a 5 percent difference in the safety factor for this example when the points along the active wedge are restricted in their movement.

Table 38

Effects of the Number of Points Used to Define the Shear Surface

Initial Point Coordinates		4-Point Surface FS* = 1.409			6-Point Surface FS* = 1.429			6-Point Surface FS* = 1.357			8-Point Surface FS* = 1.349			13-Point Surface FS* = 1.359		
		Points Used	Final Location		Points Used	Final Location		Points Used	Final Location		Points Used	Final Location		Points Used	Final Location	
X	Y		X	Y		X	Y		X	Y		X	Y		X	Y
-185.0	35.0	✓	-186.0	35	✓	-182.7	34.6	✓	-181.0	34.3	✓	-184.7	35.0	✓	-183.0	34.7
-178.2	30.0				✓	-179.0	31.2							✓	-178.4	29.7
-164.6	20.0				✓	-164.2	21.1				✓	-164.9	20.3	✓	-164.2	20.8
-157.8	15.0										✓	-158.6	13.6	✓	-158.2	14.0
-151.0	10.0	✓	-150.5	10.9	✓	-150.3	11.2	✓	-151.5	10.6	✓	-149.7	10.6	✓	-150.1	12.1
-140.0	10.0													✓	-140.1	10.6
-130.0	10.0							✓	-129.3	10.1				✓	-130.3	10.2
-120.0	10.0													✓	-119.9	10.6
-110.0	10.0							✓	-110.2	10.2	✓	-111.0	10.8	✓	-109.9	11.7
-100.0	10.0													✓	-100.3	11.2
-90.0	10.0	✓	-91.2	10.7	✓	-94.5	10.9	✓	-91.5	10.7	✓	-91.8	10.0	✓	-92.2	12.0
-85.5	15.0										✓	-84.0	12.2	✓	-84.5	14.5
-80.0	19.0	✓	-73.4	16.8	✓	-64.8	13.9	✓	-72.1	16.4	✓	-72.6	16.5	✓	-72.9	16.6
A**			B**			C**			D**			E**			F**	

Initial Point Coordinates		9-Point Surface FS* = 1.343			11-Point Surface FS* = 1.349			7-Point Surface FS* = 1.347			7-Point Surface FS* = 1.413		
		Points Used	Final Location		Points Used	Final Location		Points Used	Final Location		Points Used	Final Location	
X	Y		X	Y		X	Y		X	Y		X	Y
-185.0	35.0	✓	-182.0	34.5	✓	-182.4	34.6	✓	-180.6	34.3	✓	-182.9	34.7
-178.2	30.0							✓	-177.2	30.5	✓	-178.3	30.0
-164.6	20.0	✓	-165.8	18.8	✓	-164.7	20.5	✓	-164.2	20.8	✓	-165.8	20.0
-157.8	15.0	✓	-158.5	13.5	✓	-158.6	13.5	✓	-158.4	14.13	✓	-159.2	15.0
-151.0	10.0	✓	-149.7	11.1	✓	-150.8	11.7	✓	-150.4	11.0	✓	-120.5	10.0
-140.0	10.0				✓	-140.0	10.2						
-130.0	10.0	✓	-130.0	10.1	✓	-130.0	10.2						
-120.0	10.0												
-110.0	10.0	✓	-110.1	10.6	✓	-110.2	11.1						
-100.0	10.0				✓	-100.0	11.0						
-90.0	10.0	✓	-92.4	10.9	✓	-92.8	12.1	✓	-94.7	10.4	✓	-120.5	10.0
-85.5	15.0	✓	-83.7	11.9	✓	-83.3	12.9						
-80.0	19.0	✓	-71.3	16.1	✓	-71.1	16.2	✓	-73.5	16.8	✓	-54.9	10.6
			G**			H**			I**			J**	

* Factor of safety.

** Letters A through J designate the shear surface.

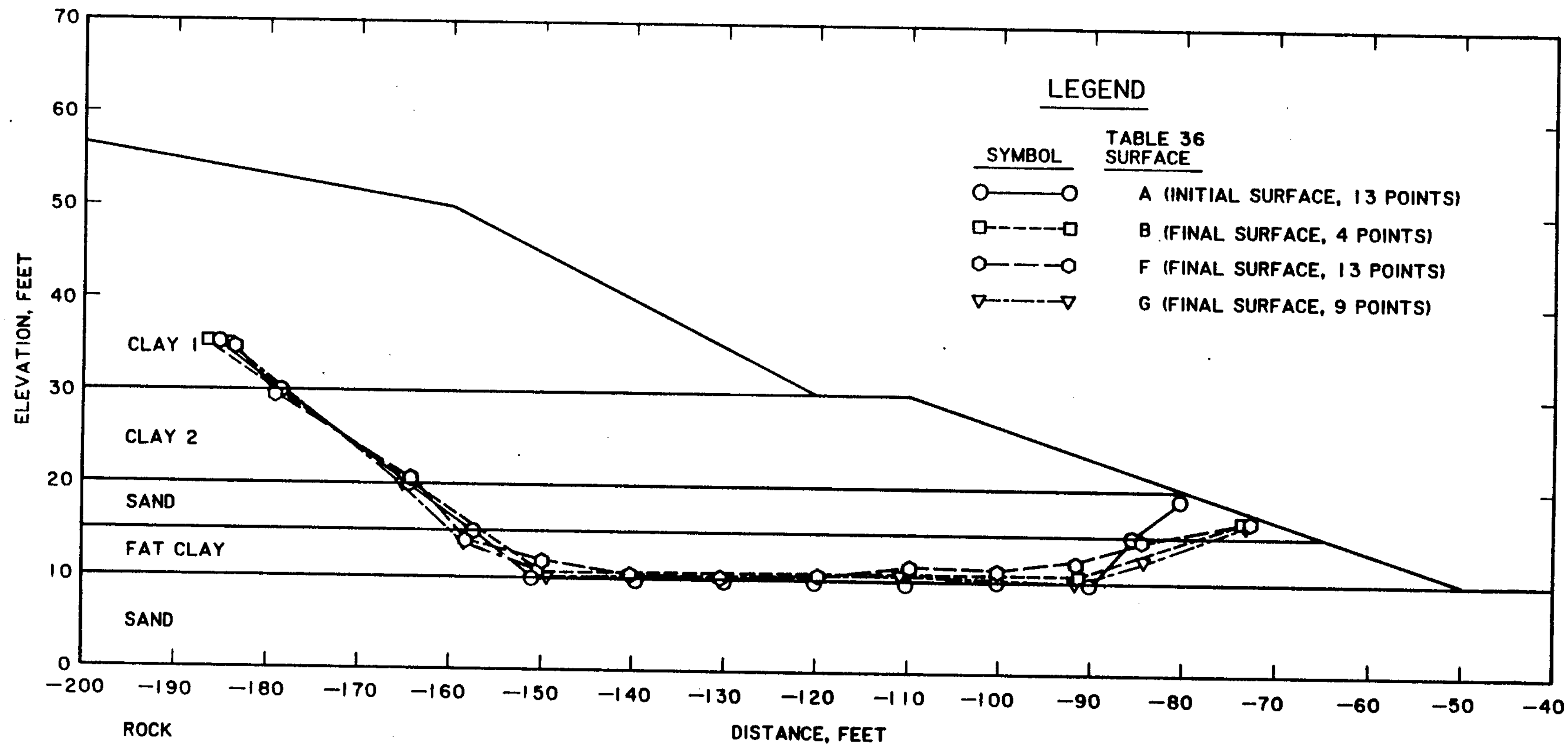


Figure 47. Initial and selected final shear surfaces illustrating the different surfaces resulting from varying the number of points used to define the shear surface

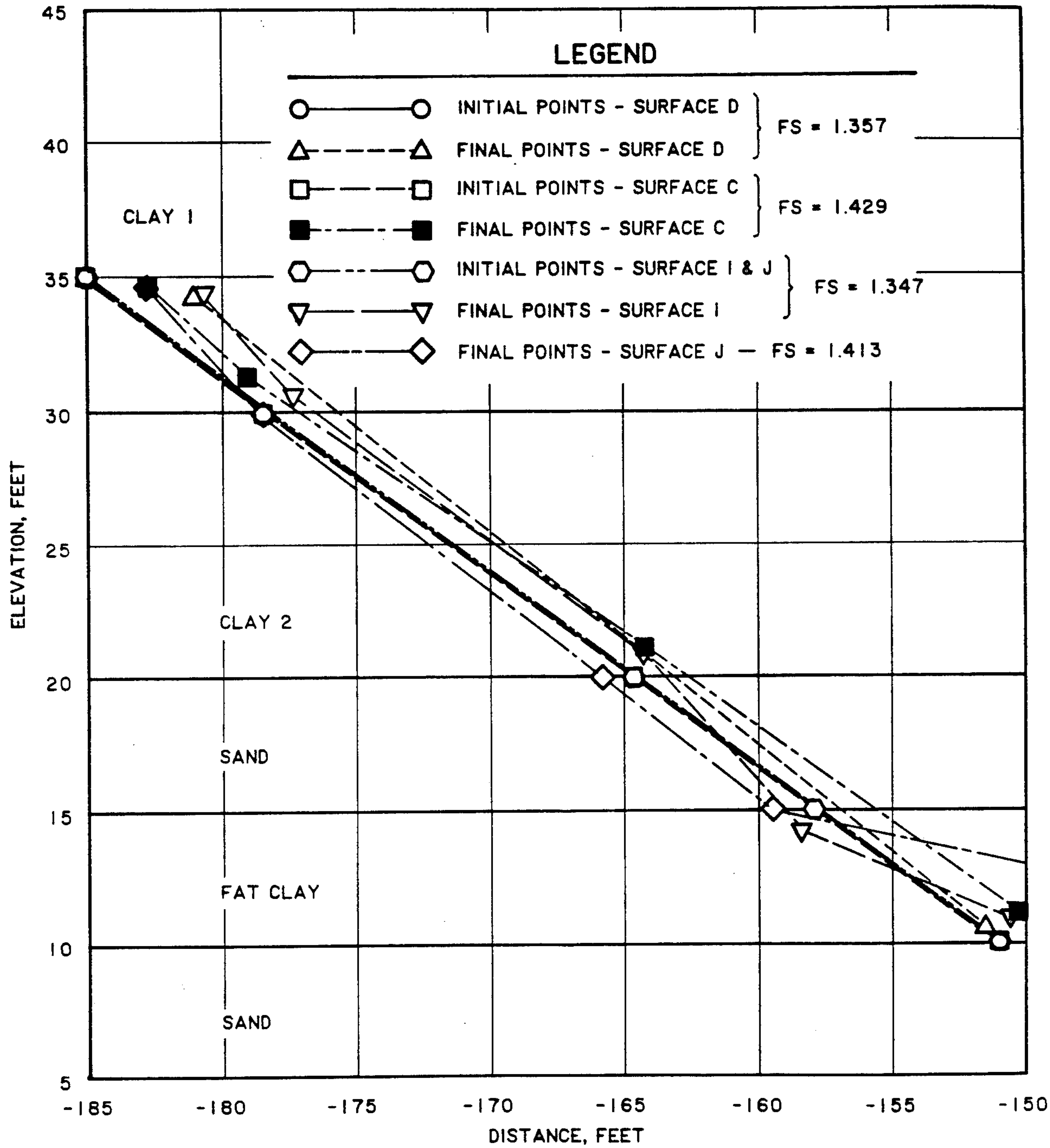


Figure 48. Active wedge portion of initial and final shear surfaces for analyses using six and seven points, illustrating the movement of points across soil boundaries

216. The last series of analyses deals with varying the width and location of the flat portion of the shear surface. There are two methods available to perform these analyses. The first is to perform searches for different base widths where the user inputs different surfaces. The other method is to restrict the direction of movement for the base end points as was illustrated for surface J in Table 38. For this series of analyses, the base widths will be varied by keeping one base point constant and varying the other. Four points will be used to define the shear surface. Table 39 lists the results where the right base point was varied. A minimum safety factor occurred for a base width of between 80 and 90 feet. Table 40 lists the results for the analyses where the right base point changed. For this case a minimum never occurred. This happens because there is only the constant cohesion parameter to define the shear strength of the fat clay, and the increase of the driving force due to the added weight of a longer base width is offset by the increased resistance force. Plots of the results listed in Tables 39 and 40 are shown in Figure 49. Based on the results of this plot and additional information about the surface profile and the horizontal extent of the stratum, the user could determine whether or not a problem exists.

217. In summary, the user must evaluate and select the best noncircular shear surface. Selecting the proper base elevation and width along with using an appropriate number and distribution of points, the user can develop the initial shear surface for a search. A range of 5 percent or more can exist for the safety factor. Also, the depth of the tension crack may need to be varied more than it was in the examples. The final search consisted of a 10-point surface shown in Figure 50. The final safety factor for this analysis is 1.28. The computer results are included as file EXAM4.OUT in Appendix E.

Table 39

Results of Analyses Involving Varied Right Base Point

Surface	Initial Points X	Initial Points Y	Final Points X	Final Points Y	Base Width, ft	Safety Factor
1	-185.0	35.0	-186.0	35.2	Initial 61	1.409
	-151.0	10.0	-150.5	10.9		
	-90.0	10.0	-91.2	10.7	Final 59.3	
	-80.0	19.0	-73.4	16.8		
2	-185.0	35.0	-185.0	35.0	Initial 40	1.616
	-150.0	10.0	-149.5	11.0		
	-110.0	10.0	-111.0	11.0	Final 38.5	
	-93.0	24.0	-85.4	21.5		
3	-185.0	35.0	-174.2	33.0	Initial 80	1.334
	-150.0	10.0	-149.3	11.8		
	-70.0	10.0	-69.7	9.4	Final 79.6	
	-65.0	14.5	-41.7	10.0		
4	-185.0	35.0	-173.2	33.0	Initial 90	1.334
	-150.0	10.0	-149.3	12.0		
	-60.0	10.0	-59.7	9.2	Final 89.6	
	-57.0	12.0	42.9	10.0		
5	-185.0	35.0	-174.2	33.2	Initial 95	1.343
	-150.0	10.0	-149.2	12.2		
	-55.0	10.0	-54.9	8.8	Final 94.3	
	-52.0	10.7	-42.8	10.0		
6	-185.0	35.0	-174.4	33.2	Initial 70	1.413
	-150.0	10.0	-149.4	10.8		
	-80.0	10.0	-85.2	9.8	Final 64.2	
	-72.0	16.5	-70.6	16.0		

Table 40

Results of Analyses Involving Changing Left Base Point

Surface	Initial Points X	Initial Points Y	Final Points X	Final Points Y	Base Width, ft	Safety Factor
1	-185.0	35.0	-186.0	35.2	Initial 61	1.409
	-151.0	10.0	-150.5	10.9		
	-90.0	10.0	-91.2	10.7	Final 59.3	
	-80.0	19.0	-73.4	16.8		
2	-165.0	35.0	-177.9	37.2	Initial 40	1.631
	-130.0	10.0	-130.0	10.2		
	-90.0	10.0	-94.2	10.2	Final 35.8	
	-80.0	19.0	-74.4	17.2		
3	-220.6	39.0	-221.6	39.2	Initial 90	1.382
	-180.0	10.0	-179.5	10.9		
	-90.0	10.0	-91.2	10.7	Final 88.3	
	-80.0	19.0	-73.4	16.8		
4	-175.0	35.0	-168.9	34.0	Initial 50	1.465
	-140.0	10.0	-139.8	10.1		
	-90.0	10.0	-94.7	10.8	Final 45.1	
	-80.0	19.0	-72.6	16.5		
5	-197.0	36.3	-198.0	36.5	Initial 70	1.394
	-160.0	10.0	-159.5	10.9		
	-90.0	10.0	-91.2	10.7	Final 68.3	
	-80.0	19.0	-73.4	16.8		
6	-209.0	37.7	-210.0	37.9	Initial 80	1.391
	-170.0	10.0	-169.5	10.9		
	-90.0	10.0	-91.2	10.7	Final 78.3	
	-80.0	19.0	-73.4	16.8		
7	-235.6	42.6	-236.6	42.8	Initial 100.0	1.376
	-190.0	10.0	-189.5	10.9		
	-90.0	10.0	-91.2	10.7	Final 98.3	
	-80.0	19.0	-73.4	16.8		

(Continued)

Table 40 (Concluded)

Surface	Initial Points X	Initial Points Y	Final Points X	Final Points Y	Base Width, ft	Safety Factor
8	-248.7	44.8	-249.7	45.0	Initial 110	1.364
	-200.0	10.0	-199.5	10.9		
	-90.0	10.0	-91.2	10.7	Final 108.3	
	-80.0	19.0	-73.4	16.8		
9	-261.8	47.0	-262.8	47.2	Initial 120	1.351
	-210.0	10.0	-209.6	10.9		
	-90.0	10.0	-91.2	10.7	Final 118.4	
	-80.0	19.0	-73.4	16.8		
10	-247.7	49.1	-275.7	49.3	Initial 130	1.336
	-220.0	10.0	-219.6	10.9		
	-90.0	10.0	-91.2	10.7	Final 128.4	
	-80.0	19.0	-73.4	16.8		
11	-235.6	42.6	-216.0	39.3	Initial 120	1.368
	-190.0	10.0	-188.2	14.1		
	-70.0	10.0	-70.4	8.4	Final 117.8	
	-65.0	14.5	-47.5	10.0		
12	-313.9	55.7	-314.9	55.9	Initial 160	1.288
	-250.0	10.0	-249.6	10.9		
	-90.0	10.0	-91.2	10.7	Final 158.4	
	-80.0	19.0	-73.4	16.8		
13	-333.4	58.9	-334.4	59.1	Initial 175	1.262
	-265.0	10.0	-264.6	10.9		
	-90.0	10.0	-91.2	10.7	Final 173.4	
	-80.0	19.0	-73.4	16.8		

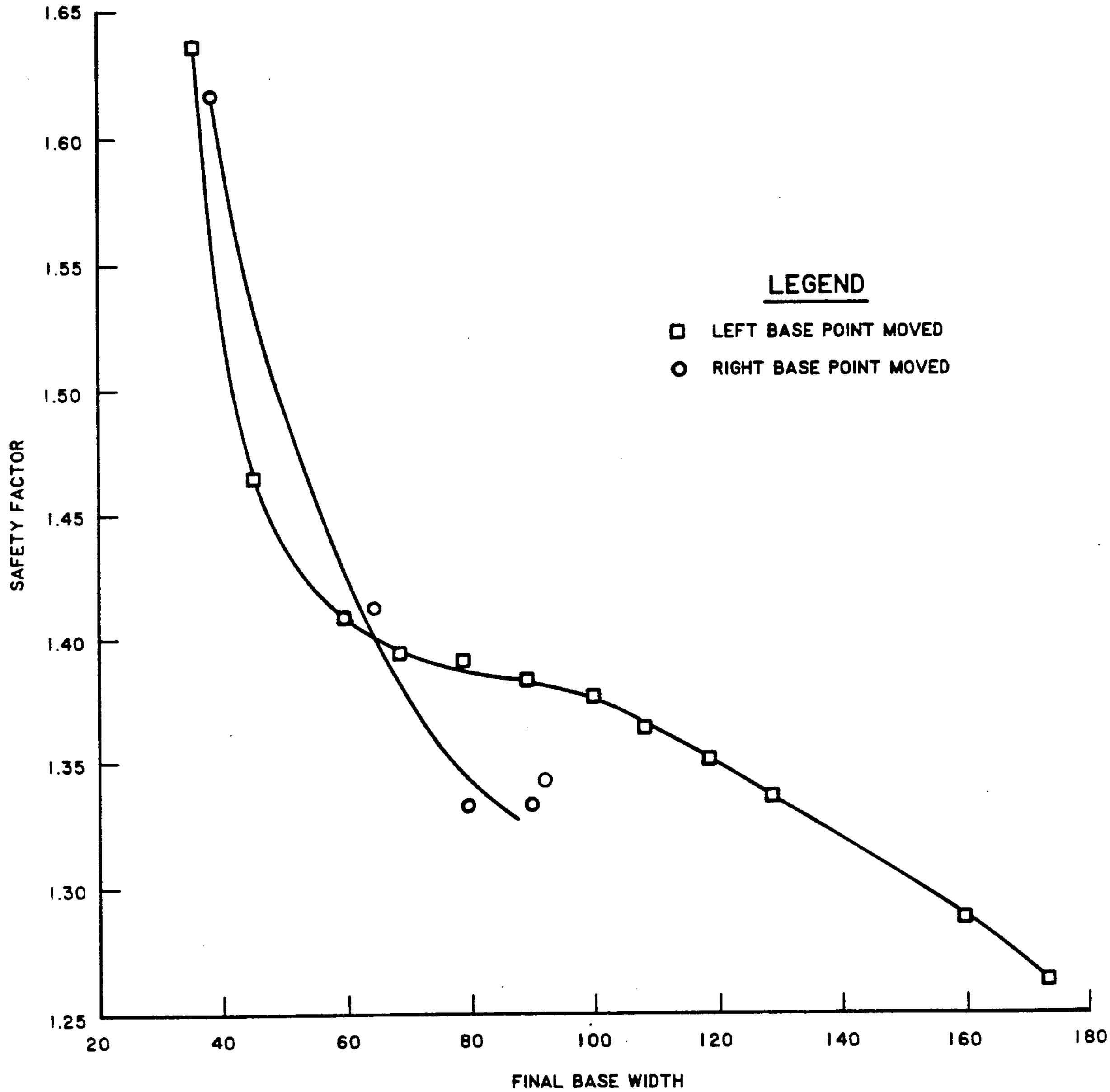


Figure 49. Plots of results of base-width analyses

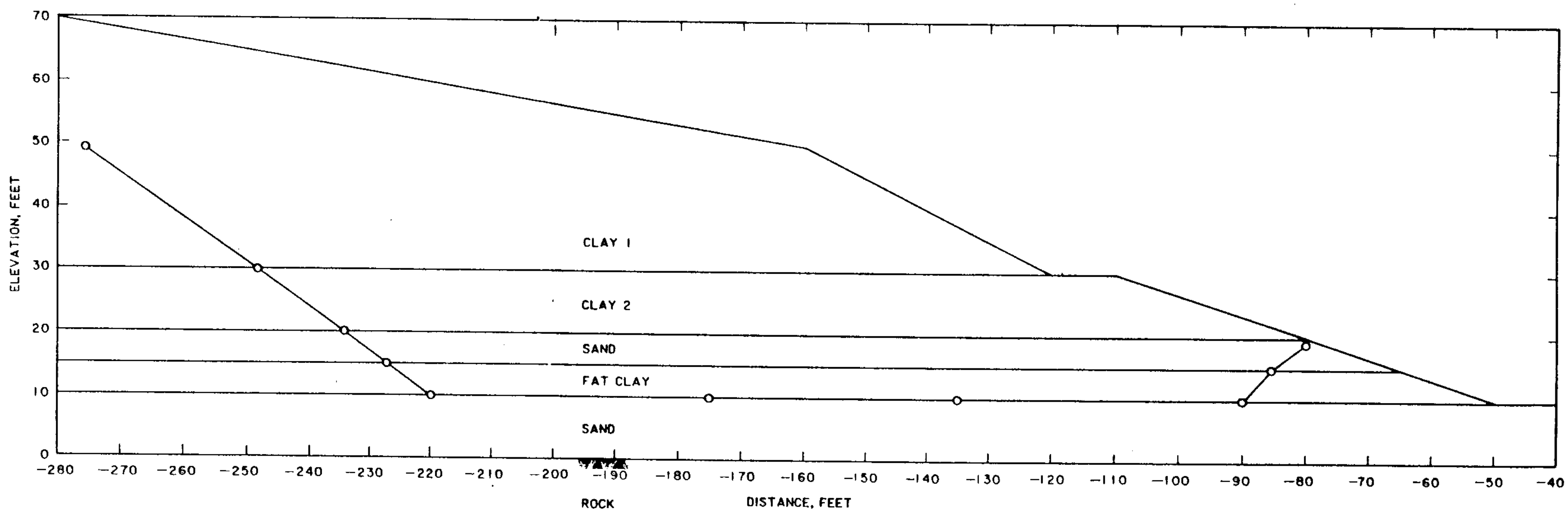


Figure 50. Final noncircular shear surface for cut slope example

Example 5: Multi-Stage Computations

218. This example illustrates the multiple step analysis procedure available in UTEXAS3 by modeling a sudden drawdown analysis. The Pilarcitos Dam example summarized by Duncan, Wright, and Wong (1990) and used in the evaluation of the multiple step computations by Wright and Duncan (1987) is used to illustrate the procedure for performing sudden drawdown analyses. Pilarcitos Dam is a homogenous rolled earthfill embankment with a crest height of 78 feet. The side slopes have a gradient of 2-1/2 to 1 for the lower 58 feet, and a 3 to 1 slope from this point to the crest. This dam experienced a slide in the upstream slope due to reservoir drawdown when the pool was lowered from elevation 692 to elevation 657 over a 43-day period. The details of the evaluation are described in the Wahler and Associates report (W. A. Wahler and Associates, 1970), and summarized by Wong, Duncan, and Seed (1983). The cross section and material properties are shown in Figure 51. The total unit weight for this embankment was 135 pcf. The effective stress shear strength parameters were $\bar{c} = 0$, $\bar{\phi} = 45°$. The strength parameters for the R envelope tangent to the Mohr circles were $c_R = 60$ psf, $\phi_R = 23°$. The objective of this example is to describe the multi-step sudden drawdown procedure.

219. Two-stage and three-stage stability computations are performed for conditions representing those that occur when a slope is subjected to undrained loading after a sufficient period of time has elapsed for the soil to have been fully-consolidated and reached a long-term, "drained" condition. The two most common instances of such loading are sudden reservoir drawdown and earthquakes. The information presented in this example summarizes the multi-stage stability procedure. The details involved in the multi-stage analysis procedure are described in Appendix A. For this example, the R envelope was tangent to the Mohr circles. Thus, Equations A.4 and A.5 are used to obtain the undrained parameters for the second stage strength shown in Figure 51.

220. Two-stage stability computations consist of two complete sets of stability calculations for each trial shear surface. The first set of stability computations is performed to calculate stresses along the shear surface, which correspond to the stresses after consolidation but prior to undrained

MATERIAL	γ PCF	S ENVELOPE		R ENVELOPE		SECOND STAGE STRENGTH PARAMETERS	
		$\bar{c}$ PSF	$\bar{\Phi}$ DEGREES	C_R PSF	Φ_R DEGREES	d_R PSF	ψ_R DEGREES
EMBANKMENT	135	0	45°	60	23°	64.10	24.39°

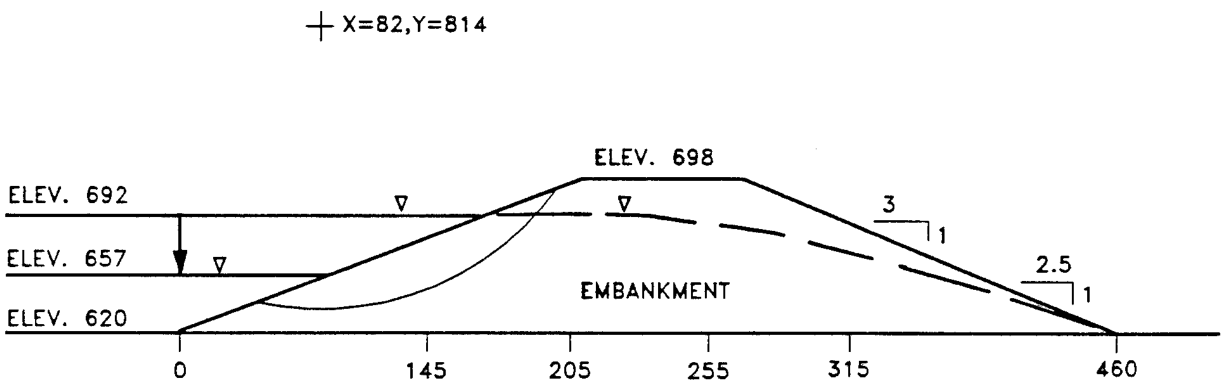


Figure 51: Example 5: Pilarcitos Dam Cross Section and Material Properties

loading. The second set of computations is performed to compute the factor of safety for undrained loading due to sudden drawdown, an earthquake or any other event that occurs rapidly enough to cause undrained loading. Different shear strengths are used for the first stage and second stage computations.

221. Three-stage stability computations consist of as many as three complete sets of stability computations for each trial shear surface. The first two sets of stability computations are the same as those for two-stage computations. A third set of computations is performed if the undrained shear strength employed in the second stage computations for any slice is greater than the shear strength that would exist if the soil were drained. In certain soils, especially those which dilate, the drained strength may be lower than the undrained strength and, accordingly, the drained strength may be more critical. Thus, the third stage of the stability computations is needed.

222. For multi-stage analysis, input data for material properties, surface pressures, concentrated forces, and piezometric surfaces must be defined for both the long-term or initial conditions and the undrained or after event conditions. An example of a multi-stage data file is shown in Figure 52. The following highlights the input data changes required for multi-stage analysis:

a. Two command words that require no additional input have been added. The command word, FIRST, for first stage computation data designates that all data which follow will be for conventional (single-stage) computations or for the first stage of multi-stage analyses. This command word is the default value and thus does not have to be included in the data file. The command word, SECOND, for second stage computational data designates that all data which follow will be for the second stage of two-stage computations. If any data are of a type that does not depend on the stage, this command word has no effect.

b. For second stage material data, the user must use one of the two options for specifying both the first and second stage data. Material data for first stage analysis must be entered even though it is overwritten by the second stage material data.

c. All surface pressure, piezometric surfaces, and concentrated force data entered after the command word "SECOND" will be used for the

heading page 21

HEADING follows— ← *command word*
Test Problem for New Version of Slope Stability Program – UTEXAS3
Conditions approximately represent those for Pilarcitos Dam
third line of heading is blank

profile line data page 22

PROFILE line data follow— ← *command word*
1 1
0.0 620.0
145.0 678.0
205.0 698.0
255.0 698.0
315.0 678.0
460.0 620.0
2 blank lines

note: First stage command word is default value

material property data page 26 (first stage data)

MATERIAL property data follow— ← *command word*
1
135 = unit weight
Conventional shear strengths
0.0 45.0
Piezometric Line
1
blank line

piezometric data page 41 (first stage)

PIEZOMETRIC line data follow— ← *command word*
1
-100.0 692.0
500.0 692.0
2 blank lines

surface pressure data page 54 (first stage)

SURFACE pressure data follow— ← *command word*
-100.0 620.0 4492.0 0.0
0.0 620.0 4492.0 0.0
145.0 678.0 873.6 0.0
187.0 692.0 0.0 0.0
blank line

SECOND-STAGE input data activated ← *command word**

material property data page 26 (second stage)

MATERIAL property data follow— ← *command word*
1
135 – unit weight
2-stage Linear strength envelopes
64.10 24.39 0.0 45.0
NO pore water pressures
blank line

surface pressure data page 54 (second stage)

SURFACE pressure data follow— ← *command word*
-100.0 0.0 2308.8 0.0
0.0 620.0 2308.8 0.0
92.5 657.0 0.0 0.0
blank line

analysis/computation data page 69

ANALYSIS/COMPUTATION data follow— ← *command word*
Circle Search
65 860 1 0.0
Tangent line elevation follows—
640.0
TWO-stage computations to be performed ← *subcommand word***
blank line

PLOT output activated ← *command word*
COMPUTE ← *command word*

* FOR ENTERING TWO-STAGE DATA
** FOR PERFORMING TWO-STAGE ANALYSIS

Figure 52. Example 5: Input Data File

second stage computations. Separate values must be entered for the initial calculations if the user wants those items included.

d. A sub-command word must be included in the ANALYSIS/COMPUTATION data for the multi-stage computations to be performed. Either the sub-command word "TWO" or "THREE" for two or three stage computations must be used.

223. A circular search was performed for the two-stage analysis using Spencer's analysis procedure, and the shear stresses on the failure plane determined from the R tests as described in Appendix A. The data file for this analysis, EXAM5.IN, is shown in Figure 52 and is included with output file, EXAM5.OUT, in Appendix E. The factor of safety for the critical circle is 1.04. The critical circle is shown on Figure 51.

224. Two and three stage computations were performed for the critical circle using all analysis procedures. There were no differences between the results for the two-stage and three-stage computations for a given analysis procedure. All analysis procedures generated the same factor of safety values.

Example 6: Embankment with Single Reinforcement Layer

225. This example describes the procedure for analysis of a single reinforcement layer in an embankment. For multiple reinforcement layers, the user is referred to the example problem J in Volume III of the UTEXAS3 User's Guide. The single reinforcement example analyzes a three foot sand embankment with a 1.5 to 1 side slope placed over a soft clay deposit. The clay material overlays a rock base. The cross-section and material properties are shown in Figure 53. The critical analysis condition for an embankment on a soft clay deposit is the end-of-construction loading which is modeled using total stresses. For this example, there are no excess pore pressures resulting from the embankment loading of the clay. Only circular shear surfaces are considered for this problem. Both Spencer's and Bishop's analysis procedures are used in the evaluation of this example. The objective of this example is to determine the reinforcement force required to increase the factor of safety above 1.3.

226. The initial step of any analysis where reinforcement materials are being used is to locate the critical shear surface without reinforcement. This shear surface will have a factor of safety below the minimum allowed, thereby indicating that reinforcement is needed. For this problem, the factor of safety for the critical shear surface was located by performing a circular search. Both Spencer's and Bishop's analysis procedure located the same shear surface which has a factor of safety of 0.8. The location of this shear surface is shown in Figure 53.

227. With the critical shear surface identified, the user determines the length and location of the reinforcement plus the allowable magnitude of the reinforcement load. In addition to length, location, and magnitude, the user must select how the reinforcement forces are to be treated in the calculations and applied to the base of the slice. This example problem assumes that the tension force in the reinforcement is applied where the shear surface intersects the reinforcement. The orientation of the force on the base of the slice is parallel to the shear surface and acts in a transverse mode. This assumption is based on the fact that large strains occur when fill is placed on a soft foundation, and that the geotextile normally will follow along with this movement.

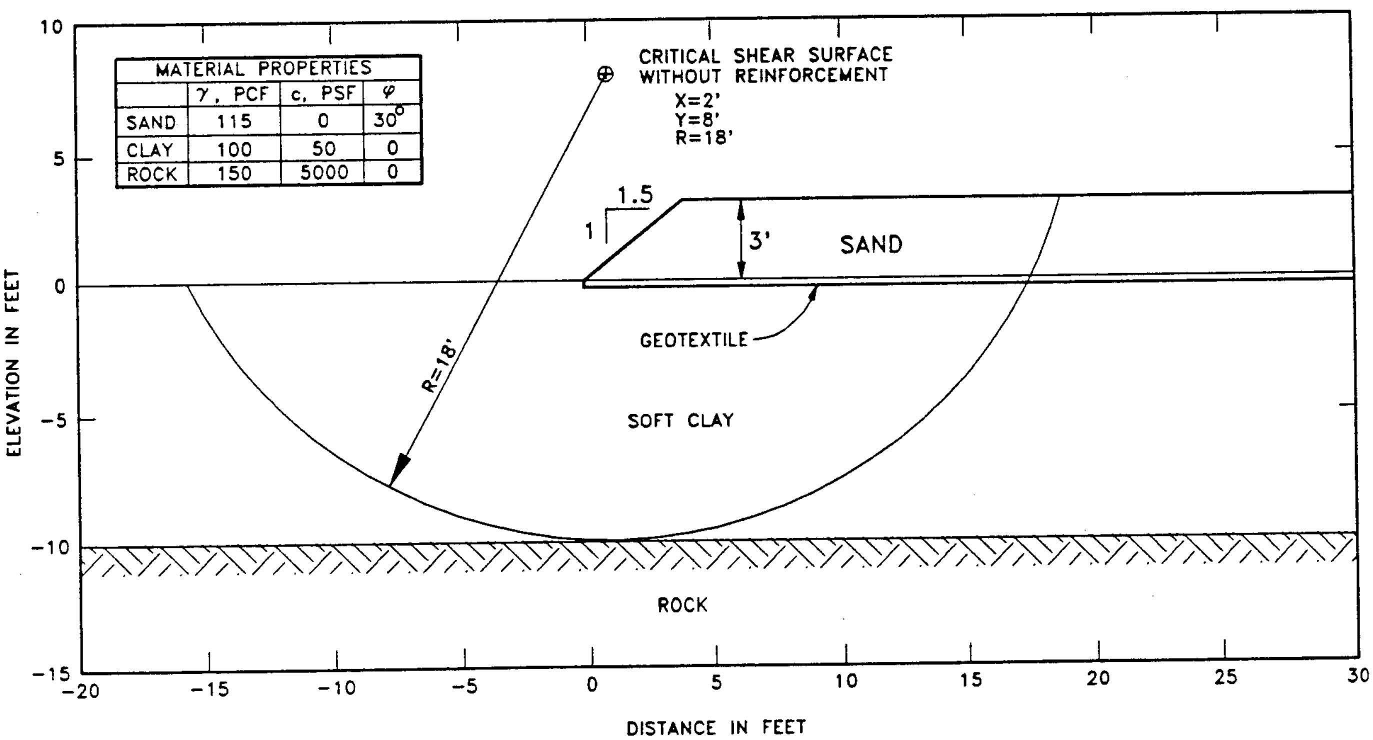


Figure 53. Example 6: Cross-Section and Material Properties

228. There are two options available to designate how the reinforcement forces are treated in the calculations and applied to the base of the slice. The options are described as follows:

a. Option 1. In this option, the reinforcement forces are calculated and applied to the boundaries between each slice as well as to the base of the slice as shown in Figure 5. When forces are applied to the boundaries between slices, they are calculated from the forces in the reinforcement at the point where the reinforcement crosses the slice boundary. Equal and opposite forces are applied to each side of the slice boundary. With this option, the side forces presented in the output represent only the forces transmitted directly through the soil.

b. Option 2. For this option, the reinforcement forces that intersect the slice boundaries are not included in the slice computations. The reinforcement forces are applied to the base of the slice on which they act as shown in Figure 6. With this option, the side forces presented in the output represent the forces in the soil plus the reinforcement forces.

229. The system of forces in both Figures 5 and 6 are statically equivalent and differ only in how the reinforcement forces are distributed among slices. In general both options should generate the same factor of safety.

230. Each of the above options are used in this example to show the influence on the safety factor. The location and forces in the reinforcement are defined by use of coordinate points where either the location or the force magnitude changes. Both longitudinal (axial) and transverse (shear) forces must be specified for each coordinate point along the reinforcement lines. The longitudinal forces in the reinforcement are considered to be positive when they are tensile; compressive forces are considered to be negative. The shear forces are considered to be positive when they act such that they produce a counter-clockwise moment on the adjoining reinforcement as shown in Figure 3. The orientation of the reinforcement force on the base of the slice is determined by the orientation of the reinforcement and an additional parameter that represents the maximum rotation of the reinforcement due to deformation. The reorientation parameter represents an angle that the rein-

forcement rotates through from its initial specified orientation. If the angle is specified as zero, the reinforcement is assumed to be oriented in the original direction of placement. If the angle is greater than zero, the reinforcement is assumed to be rotated through the specified angle, but not past the point where it becomes tangent to the shear surface. The direction that the reinforcement is assumed to be rotated depends on the direction in which the slope faces, as shown in Figure 4. The directions of rotation shown in this figure correspond to positive rotation angles; negative rotation angles produce rotations in the opposite directions.

231. To determine the required force needed to raise the factor of safety above 1.0 or a specified value, several trial force magnitudes (ranging from 250 lbs/ft into the cross-section to 1500 lbs/ft into the cross-section) are considered. For this example, the required factor of safety is 1.3. The results of analyzing just the critical shear surface identified without reinforcement with the range of reinforcement forces and both options 1 and 2 are shown in Table 41 and plotted in Figure 54. For all analyses, the reinforcement load was zero under the embankment slope and increased to the specified load 2 feet beyond the slope crest. An example of a complete data file is shown in Figure 55 and included as EXAM6.IN in Appendix E.

232. For this cross section and shear surface, both options generated the same factor of safety for a given reinforcement load. Thus for this type of reinforcement problem, either option could be used and it is suggested that both should be used as a check. If differences in the factor of safety occur, the user should investigate the output tables to evaluate why the difference occured.

233. Using a reinforcement force of 1100 lbs/ft into the cross-section with Option 2, separate circular searches were performed using both analysis procedures to determine if the critical shear surface with reinforcement is the same as without reinforcement. The results of the searches are shown in Figure 56.

234. The nonconvergence of the Spencer's procedure for the higher reinforcement loads indicates that the assumption of the reinforcement parallel to the shear surface at point A may not be totally correct or Spencer's procedure will not handle increased side forces above that value which would cause the soil mass to be "pulled" up hill. The Bishop procedure gives reasonably cor-

Table 41
Results of Adding Reinforcement to Critical Shear Surface

Reinforcement Load (lbs/lin ft)	Safety Factor			
	Option 1		Option 2	
	Spencer	Bishop	Spencer	Bishop
0	0.79	0.79	0.79	0.79
250	0.88	0.88	0.88	0.88
500	0.98	0.98	0.98	0.98
750	1.11	1.11	1.11	1.11
1000	1.29	1.28	1.30	1.28
1250	1.54	1.52	NC	1.52
1500	NC*	1.85	NC	1.85

* NC indicates no convergence

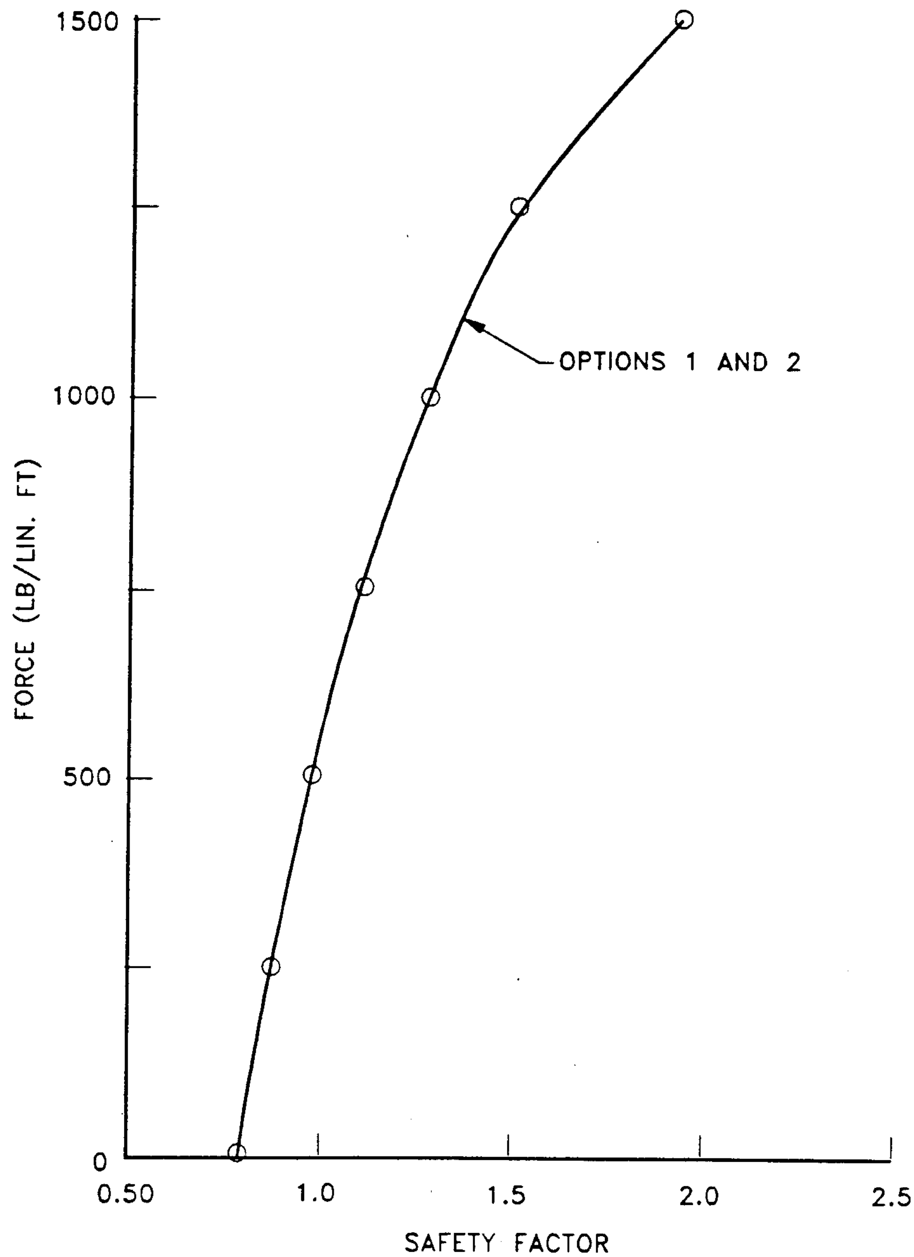


Figure 54. Plot of factor of safety change with change in reinforcement force

```
HEADING
FILE REI1C.IN EXAMPLE FOR SINGLE LAYER OF REINFORCEMENT EMBANKMENT
ON A SOFT FOUNDATION 3 FEET OF SAND OVER THE GEOTEXTILE.
REINFORCEMENT FORCE PARALLEL TO SLICE BASE AND OPT. 2 USED.
 PROFILE
   1 1 SAND LAYER
   0 0
   4 3
   25 3

   2 2 SOFT CLAY FOUNDATION
   -25 0
    25 0

   3 3  ROCK
   -25 -10
    25 -10


 MATERIAL PROPERTIES
   1 SAND LAYER
    115
    CONVENTIONAL SHEAR
    0 30
    NO PORE PRESSURE
   2 SOFT CLAY FOUNDATION
    100
    CONVENTIONAL SHEAR - UNCONFINED COMPRESSIVE STRENGTH
    50 0
    NO PORE PRESSURE
   3 ROCK
    150
    CONVENTIONAL SHEAR
    5000  0
    NO PORE PRESSURE

PLOT
 REINFORCEMENT LINES
  1 90 2
  0 0 0 0
  4 0 0 0
  6 0 250 0
  25 0 250 0


ANALYSIS/COMPUTATION
 CIRCLE
  2 8 18

COMPUTE
```

Figure 55. Example 6: Input data file for reinforcement force of 250 lb/lin ft

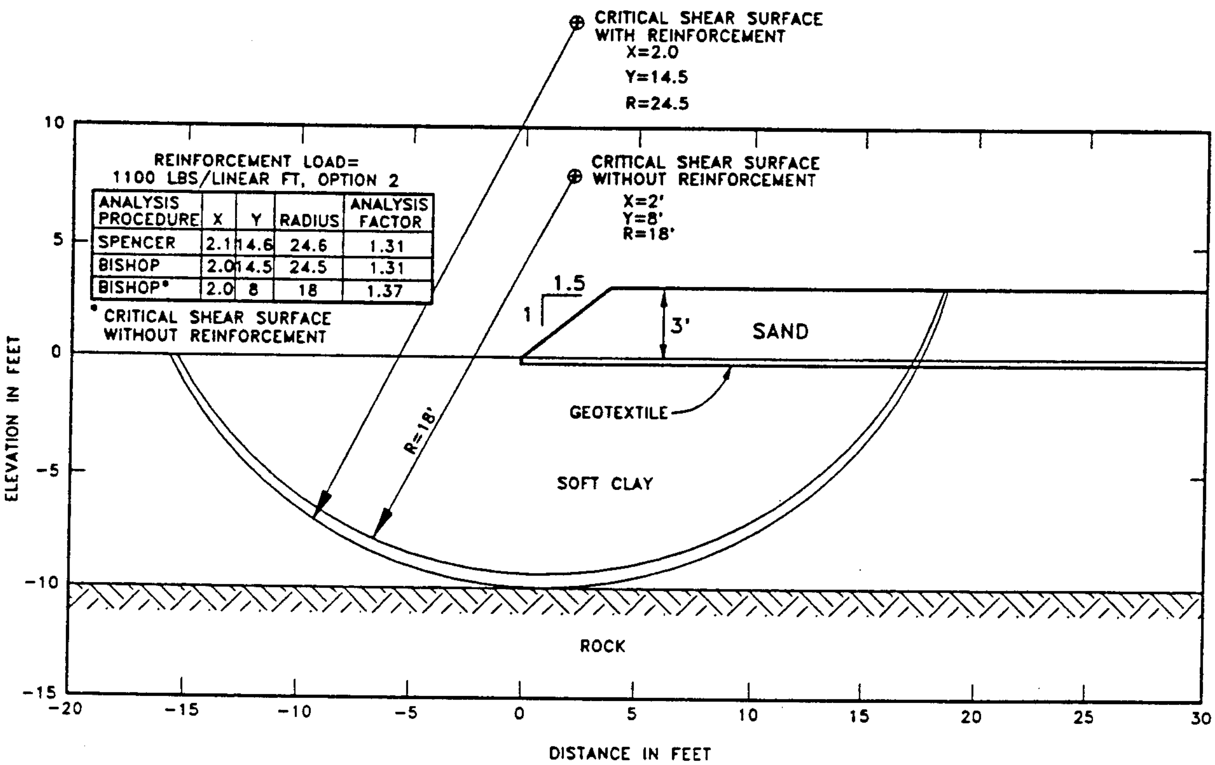


Figure 56. Example 6: Results of circular search analyses

rect solutions for this type of problem because of the circular shear surface, the $\phi = 0$ material, and reinforcement force being parallel to the shear surface is taken as a movement about the center of the shear surface.

235. The designer must be aware of several items when using the program UTEXAS3 with reinforcement. A problem could occur at the toe of the shear surface where the shear surface would cross a reinforcement layer a second time and the tension force would be modeled at that slice as a force trying to pull the soil mass down the slope. This problem greatly reduces the factor of safety. Another item concerns negative forces between slices or when the side force location is above or below the slice. These conditions are indicated by caution or warning messages and generally indicate that the tensional force in the reinforcement located in the slice generating the condition is too large and should be reduced. The UTEXAS3 analysis is a limit equilibrium method and cannot predict the actual load to be developed in the reinforcement layers or the amount of strain that will take place. The strain compatibility of the soil and reinforcement are critical to a correct modeling of the stability analysis.

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APPENDIX A - MULTI-STAGE STABILITY COMPUTATIONS (Wright 1991)

Two-stage and three-stage stability computations are performed for conditions representing those that occur when a slope is subjected to undrained loading after a sufficient period of time has elapsed for the soil to have been fully-consolidated and reached a long-term, "drained" condition of equilibrium and the pore pressure changes resulting from that loading increment are unknown. The two most common instances of such loading are sudden reservoir drawdown and earthquakes.

Two-stage stability computations consist of two complete sets of stability calculations for each trial shear surface. The first set of stability computations is performed to calculate the effective normal and the shear stresses along the shear surface, which correspond to the stresses after consolidation but prior to undrained loading; the second set of computations is performed to compute the factor of safety for undrained loading due to sudden drawdown, an earthquake or any other event that occurs rapidly enough to cause undrained loading. Different shear strengths are used for the first stage and second stage computations as described in the next sections.

Three-stage stability computations consist of as many as three complete sets of stability computations for each trial shear surface. The first two sets of stability computations are the same as those for two-stage computations. A third set of computations is performed if the undrained shear strength employed in the second stage computations for some of the slices is greater than the shear strength that would exist if the soil were drained. In certain soils, especially those which dilate, the drained strength may be lower than the undrained strength. Since the possibility can not be discounted that partial drainage does not take place in a short time period, the drained strength may be more critical. Thus, the third stage of the stability computations is required.

In general, two-stage stability computations are appropriate for earthquake loadings, where the loads produced by the earthquake will not remain for a long enough period of time for the soil to drain. Three-stage stability computations are appropriate for sudden drawdown and are used in the procedure recommended by Duncan, Wright and Wong (1990).

First–Stage Computations

The purpose of the first set of computations is to compute the effective normal stresses and the shear stresses along the shear surface (on the base of each slice) before undrained loading. These correspond to the stresses to which the soil is consolidated before undrained loading occurs. The stresses computed from the first–stage are used to estimate undrained shear strengths, which are then used in the second set of stability computations. The first stage stability computations are performed using slope stability analysis procedures which are identical to the ones normally used to compute the factor of safety for long–term, "drained", stability. Effective stress shear strength properties and appropriate values of pore water pressure and external surface loads prior to undrained loading are used. In the case of sudden drawdown the external loads and pore water pressures would correspond to those assumed to exist before drawdown. Similar conditions would be assumed for earthquake loading.

Although a factor of safety is calculated for each trial shear surface in the first stage computations, the purpose of the computations is to compute stresses along the assumed shear surfaces; the factor of safety computed with the first stage computations is of no interest. The effective normal stresses on the shear surface, $\bar{\sigma}_{fc}$, are calculated for individual slices from:

$$\bar{\sigma}_{fc} = \frac{N}{\Delta \ell} - u \qquad \text{A.1}$$

where, N is the total normal force on the base of the slice, $\Delta \ell$ is the length of the base of the slice, and u is the pore water pressure at the center of the base of the slice. The effective stress, $\bar{\sigma}_{fc}$, is assumed to be the effective stress to which the soil is consolidated prior to undrained loading. The shear stresses on the base of each slice, τ_{fc}, are calculated from:

$$\tau_{fc} = \frac{S}{\Delta \ell} \qquad \text{A.2}$$

where, S is the shear force on the base of the slice.

Second-Stage Computations

Once the effective normal stress and shear stress are calculated for the base of each slice from the first stage computations, appropriate undrained shear strengths must be determined for use in the second stage computations. The undrained shear strengths are then used to compute a factor of safety for the undrained loading due to sudden drawdown or earthquake loading. The procedures used to determine the undrained shear strength are based on the procedures proposed by Duncan, Wright and Wong (1990) for stability computations for sudden reservoir drawdown. The procedures for determining shear strengths for the second stage computations are similar to those originally recommended by Lowe and Karafiath (1960) with the further simplification that linear interpolation is used to estimate the effects of anisotropic consolidation. EM 1110-2-1902 (Headquarters, 1970) does not account for the anisotropic consolidation and uses the minimum of the combined R and S envelopes for the shear strengths.

"Two-Stage" Strength Envelopes

Two shear strength envelopes are used to define the shear strengths for the second stage computations (Figure A.1). Both envelopes represent a relationship between shear strength, expressed as the shear stress on the failure plane at failure, τ_{ff}, and the effective normal stress on the failure plane at consolidation, $\bar{\sigma}_{fc}$. The first envelope is the conventional effective stress shear strength envelope. This envelope is identical to the envelope used for long-term stability computations and the first-stage of multi-stage stability computations. The envelope on a τ_{ff} vs. $\bar{\sigma}_{fc}$ diagram is identical to the effective stress envelope on a conventional Mohr-Coulomb (τ–σ) diagram. The envelope has a slope, ψ_s, equal to the effective stress friction angle, $\bar{\phi}$, for the soil, and an intercept, d_s, equal to the effective stress cohesion value, $\bar{c}$ for the soil. The second envelope is derived from the results of consolidated-undrained (CU, R) type triaxial shear tests performed on specimens consolidated isotropically. The envelope can be derived directly by computing and plotting τ_{ff} versus $\bar{\sigma}_{fc}$. The shear stress on the failure plane at failure is computed from:

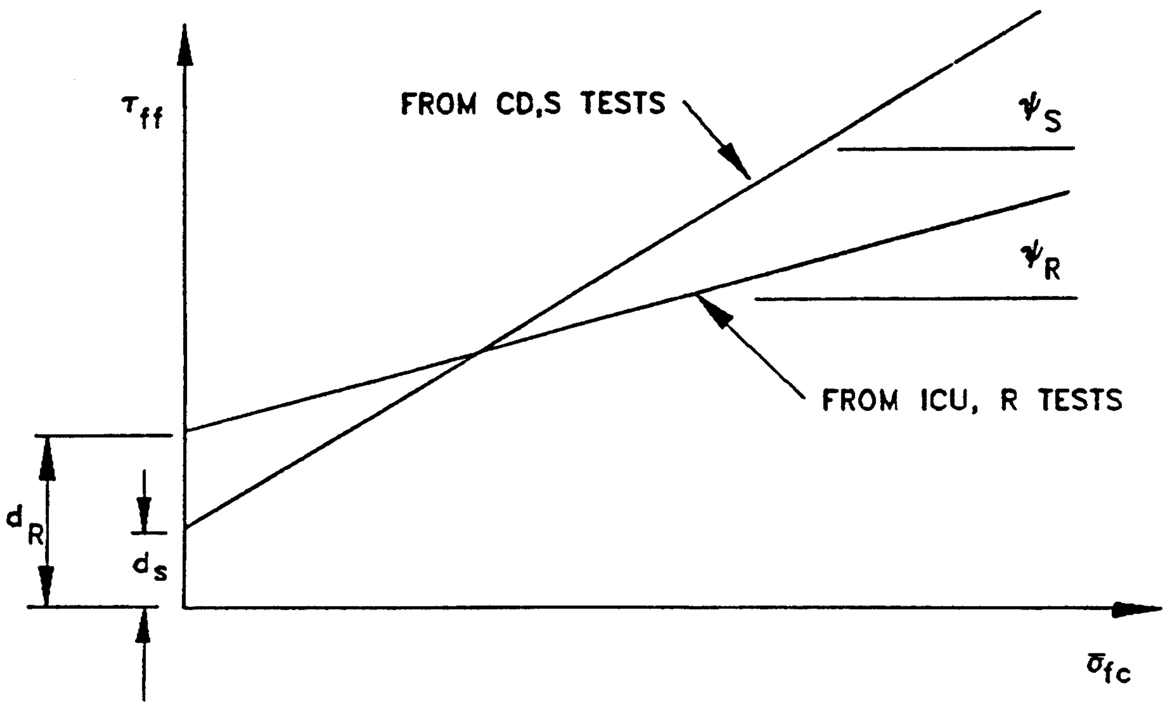


Figure A.1 Shear Strength Envelopes Used to Compute Shear Strengths for Second Stage of Two-Stage Stability Computations.

$$\tau_{ff} = \frac{(\sigma_1 - \sigma_3)_f}{2} \cos \bar{\phi} \qquad \text{A.3}$$

where $(\sigma_1 - \sigma_3)_f$ is usually taken as the maximum (peak) principal stress difference and $\bar{\phi}$ is the angle of internal friction expressed in terms of effective stresses. For soils whose stress-strain response does not show a pronounced peak or where a peak is reached at large strains, failure may be selected at some arbitrary, smaller value of strain, e.g., 15% axial strain. For soils which exhibit a significant reduction in strength $(\sigma_1 - \sigma_3)$ during undrained loading it may be appropriate to use stresses less than the peak values to plot the failure envelopes. The friction angle, $\bar{\phi}$, in Eq. A.3 is identical to the friction angle from the effective stress failure envelope. The effective stress on the failure plane after consolidation, $\bar{\sigma}_{fc}$, which is used to plot the second strength envelope is identical to the effective stress to which the specimen was consolidated prior to shear $(\bar{\sigma}_{fc} = \bar{\sigma}_{3c})$.

The τ_{ff} versus $\bar{\sigma}_{fc}$ envelope from consolidated-undrained shear tests can also be computed from the cohesion and friction angle, c_R and ϕ_R, respectively, obtained from the "R" envelope plotted on a conventional Mohr-Coulomb diagram (Figure A.2). The R envelope, often mistakenly referred to as the "total stress" envelope, is obtained from circles on a Mohr-Coulomb diagram, which are plotted with the effective minor principal stress being the value at consolidation, $\bar{\sigma}_{3c}$, and the principal stress difference being the principal stress difference at failure, $(\sigma_1 - \sigma_3)_f$. Such circles do not constitute proper Mohr's circles, because one stress, $\bar{\sigma}_{3c}$, is at consolidation and the other stress, $(\sigma_1 - \sigma_3)_f$, is at failure. However, the circles are commonly plotted and used to determine a "total stress" (R) envelope. The envelope may be constructed either as a line drawn tangent to the circles on the Mohr-Coulomb diagram (Figure A.3a) or as a line passing through points representing the stresses on the failure plane (Figure A.3b); points representing stresses on the failure plane are located at an angle $\bar{\phi}$ from the point of maximum shear stress, as shown in Figure A.3b. The slope and intercept of such an envelope are expressed by a friction angle, ϕ_R, and cohesion value, c_R, respectively. If the envelope is drawn so that it is tangent to the circles (Figure A.3a), the equations representing the corresponding slope (ψ_R) and intercept (d_R) of the τ_{ff} versus $\bar{\sigma}_{fc}$ envelope are:

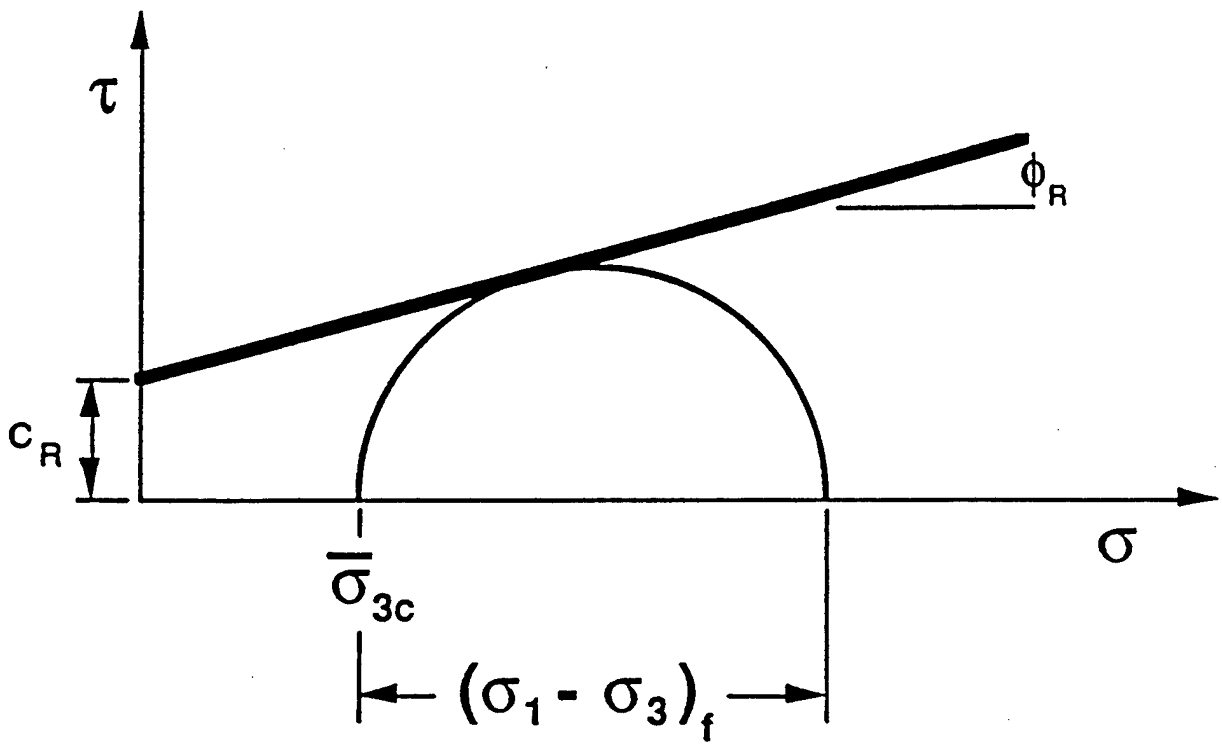
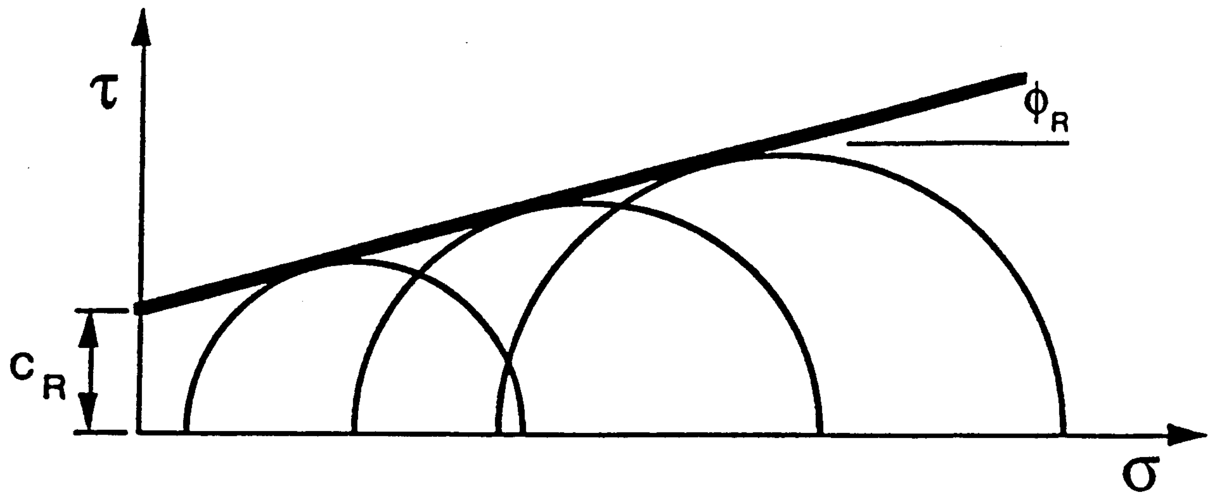
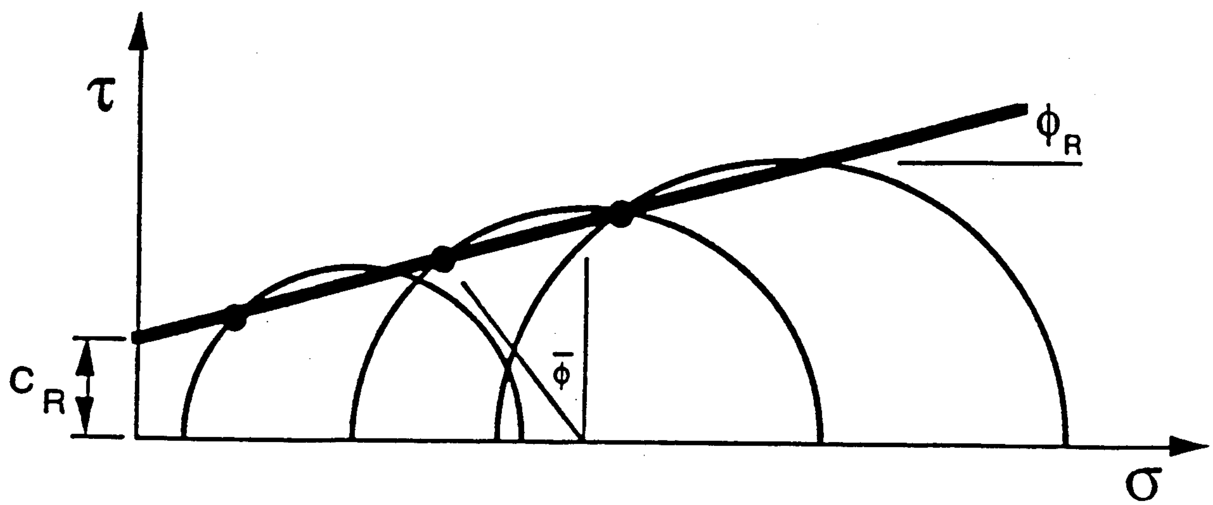


Figure A.2 R ("Total Stress") Envelope from Consolidated-Undrained Triaxial Shear Tests.



a - R ("Total Stress") Envelope Tangent to Circles.



b - R ("Total Stress") Envelope Through Points Representing Stresses on the Failure Plane.

Figure A.3 Methods of Representing R ("Total Stress") Envelopes.

$$d_R = c_R \left(\frac{\cos \phi_R \cos \bar{\Phi}}{1 - \sin \phi_R} \right) \qquad \text{A.4}$$

and,

$$\psi_R = \tan^{-1} \left(\frac{\sin \phi_R \cos \bar{\Phi}}{1 - \sin \phi_R} \right) \qquad \text{A.5}$$

If the envelope is drawn so that it passes through points on the circles corresponding to the stresses on the failure plane (Figure A.3b), the equations representing the corresponding slope (ψ_R) and intercept (d_R) of the τ_{ff} versus $\bar{\sigma}_{fc}$ envelope are:

$$d_R = \frac{c_R}{1 + \dfrac{(\sin \bar{\Phi} - 1)}{\cos \bar{\Phi}} \tan \phi_R} \qquad \text{A.6}$$

and,

$$\psi_R = \tan^{-1} \left(\frac{\tan \phi_R}{1 + \dfrac{(\sin \bar{\Phi} - 1)}{\cos \bar{\Phi}} \tan \phi_R} \right) \qquad \text{A.7}$$

EM 1110-2-1902 (Headquarters, Department of the Army, 1970) indicates that the strength envelopes are customarily drawn tangent to the Mohr circles. This is correct when effective stresses are plotted, but is slightly in error if total stresses for Q and R tests are plotted, as the strength envelope should pass through the points on Mohr circles. The error is considered unimportant for undisturbed soils because of the compensating effect of disturbance caused by sampling and testing. However, for compacted specimens,

which are presumed to have negligible disturbance before testing, the strength envelopes should be drawn through points on the Mohr envelopes representing stresses on the failure plane.

The two shear strength envelopes used to define the strengths for the second stage computations are entered as "two-stage" strengths in the input data for UTEXAS3 (See Group C Data). The envelopes are entered as part of the input data for the second stage computations. Although the effective stress envelope will have already been entered once with the input data for the first stage computations, it must be entered again with the data for the second stage computations. The envelopes may be either straight lines (Strength Option 6) or nonlinear envelopes (Strength Option 7), specified by a series of points along each envelope.

Calculation of Undrained Shear Strengths for Second Stage

Shear strengths for the second stage computations are determined automatically in UTEXAS3, using the effective stresses calculated in the first-stage computations and the two shear strength envelopes shown in Figure A.1. Shear strengths are calculated slice-by-slice for each slice as follows: First shear strengths, τ_{ff-R} and τ_{ff-S}, are determined from each of the two envelopes based on the effective normal stress, $\bar{\sigma}_{fc}$, calculated from the first stage stability computations (Eq. A.1). Next, the effective principal stress ratio at consolidation, $\bar{K}$ (= K_c = $\bar{\sigma}_{1c}/\bar{\sigma}_{3c}$), is then calculated from:

$$\bar{K} = \frac{\bar{\sigma}_{fc} + \tau_{fc}\,\dfrac{\sin \Phi + 1}{\cos \bar{\Phi}}}{\bar{\sigma}_{fc} - \tau_{fc}\,\dfrac{\sin\bar{\Phi} - 1}{\cos \bar{\Phi}}} \qquad \text{A.8}$$

where, $\bar{\sigma}_{fc}$ and τ_{fc} are the effective normal stress and the shear stress, respectively, on the shear surface from the first stage computations. Equation A.8 is derived assuming that the orientation of the principal stresses at consolidation is the same as it would be at failure (as originally suggested

by Lowe and Karafiath 1960). The effective principal stress ratio at failure, K_f ($= \bar{\sigma}_{1f}/\bar{\sigma}_{3f}$) is also calculated. It is calculated from:

$$K_f = \frac{(\bar{\sigma}_{fc} + \bar{c} \cos \bar{\Phi})\ (1 + \sin \bar{\Phi})}{(\bar{\sigma}_{fc} - \bar{c} \cos \bar{\Phi})\ (1 - \sin \bar{\Phi})} \qquad \text{A.9}$$

Finally, the shear strength to be used in the second stage computations is computed by linear interpolation between the two shear strengths, $\tau_{ff\text{-}R}$ and $\tau_{ff\text{-}S}$, based on the corresponding effective principal stress ratios at consolidation. The shear strength determined in this manner is expressed by:

$$\tau_{ff} = \frac{(K_f - \bar{K})\,\tau_{ff\text{-}R} + (\bar{K} - 1.0)\,\tau_{ff\text{-}S}}{K_f - 1} \qquad \text{A.10}$$

In some cases the denominator in the expressions for either $\bar{K}$ or K_f can become negative because the corresponding minor principal stress, $\bar{\sigma}_{3c}$ and $\bar{\sigma}_{3f}$, respectively, become negative. The effective minor principal stress at consolidation is given by:

$$\bar{\sigma}_{3c} = \bar{\sigma}_{fc} + \tau_{fc} \frac{\sin \bar{\Phi} - 1}{\cos \bar{\Phi}} \qquad \text{A.11}$$

The minor principal stress at failure is given by:

$$\bar{\sigma}_{3f} = (\ \bar{\sigma}_{fc} - \bar{c} \cos \bar{\Phi})\ \frac{(1 - \sin \phi)}{\cos^2 \bar{\Phi}} \qquad \text{A.12}$$

If either of these two stresses ($\bar{\sigma}_{fc}$ or $\bar{\sigma}_{3f}$) become zero or negative, the shear strengths are not interpolated using Eq. A.10. Instead the lower of the two strengths, $\tau_{ff\text{-}R}$ and $\tau_{ff\text{-}S}$, is used as the shear strength for the second stage stability computations.

Once appropriate shear strengths (τ_{ff}) are determined, the shear strengths are assigned as "cohesion" values for each slice and ϕ is set equal to zero for the second stage stability computations. Strengths are considered to be defined in terms of total stresses and pore water pressures can be set equal to zero. (Actually the pore water pressure is immaterial if ϕ is zero). The shear strength used for the second stage computations is then set equal to τ_{ff} ($c = \tau_{ff}$, $\phi = 0$).

Freely-Draining Materials

In some instances materials may be freely-draining and will not experience undrained loading even under conditions of relatively rapid loading and unloading. This may be particularly true for sudden drawdown and is less likely to be the case for earthquake loading. When materials exist, which are clearly freely-draining, the procedures used to estimate undrained strengths for the second stage of the two-stage analyses are not appropriate. The shear strengths for such materials should be represented by the same effective stress shear strength envelope and strength option (e.g., Option 1) that was used to represent the strengths for the first stage computations. In this case pore water pressures corresponding to the pore pressures for the drained condition after drawdown or earthquake loading should be specified. This applies only to the materials which are clearly free-draining. Of course, if all materials are free draining, there would be no purpose in performing multi-stage stability computations.

Loading Conditions

Surface pressures and concentrated forces for the second stage stability computations should represent the ones that will exist during and/or immediately after undrained loading. In the case of sudden drawdown the surface pressures would be the ones immediately after drawdown. In the case of earthquake loading the surface pressures for the second stage would be the ones that exist during the earthquake. They might either be the same as the values used for the first stage or values might be altered to reflect hydrodynamic values. The seismic coefficient used to represent earthquake loads is only

applied in the second and third stage stability computations; the seismic coefficient will not be applied in the first stage of multi-stage computations.

Third-Stage Computations

Third stage computations are performed for cases where the possibility exists that drainage may occur, even during sudden loading, and the drained strength may be lower than the undrained strength. Three-stage stability computations are recommended for sudden drawdown, especially for materials which may dilate and become weaker as they drain.

When three-stage computations are performed, the first two stages are identical to those for two-stage computations. Once the second stage computations are completed a check is made of each slice, on a slice-by-slice basis, to determine if the drained strength might be lower than the undrained strength, which was used in the second stage stability computations. First, the effective normal stress that would exist for drained conditions is estimated from:

$$\bar{\sigma}_{fc} = \frac{N}{\Delta \ell} - u \qquad \text{A.13}$$

where N is the total normal force on the base of the slice calculated in the second stage stability computations and u is the pore water pressure that would exist once drainage and reestablishment of steady-state equilibrium has occurred following the undrained loading (sudden drawdown, earthquake, etc.). This requires that the pore water pressure that would exist once drainage has occurred be specified with the input data. This is done by specifying pore water pressures with the data for the second stage computations; the pore water pressures are ignored for the second stage computations, but used to

estimate drained strengths for the third stage computations.[1] The effective normal stress calculated from Eq. A.13 is used to compute the drained shear strengths from the drained (effective stress) failure envelope which was entered and used for the second stage computations. If the drained strength is lower than the undrained strength that was used for the second stage stability computations, effective stress shear strength parameters ($\bar{c}$ and $\bar{\phi}$) and appropriate pore water pressures are assigned to the particular slice where this occurs. If the drained strength is higher than the undrained strength, the strength for the particular slice is not changed.

Once the strengths are checked for each slice and any changes are made, a third set of stability computations is made using the revised strengths. The factor of safety calculated for the third stage is then taken as the appropriate value for the trial shear surface being considered. Of course, if the drained strengths were found to be higher for all slices when checked at the end of the second stage, no third set of stability computations is required and the factor if safety is the value computed in the second stage computations.

No separate sets of input data are required for three-stage computations in addition to the data entered for the second stage computations. Data for both the second and third stage computations are entered with the "second-stage" input data. However, when three-stage computations are performed pore water pressures corresponding to those that would exist if drainage occurs must be entered with the two-stage strength data. This may require that piezometric lines or other representations of pore water pressure be entered for the second stage even though the strength may ultimately be governed by the undrained condition and the pore water pressures may not be used directly in the final computations for the factor of safety.

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[1]This applies only to materials which have been designated as having "twostage" (undrained) strengths (Strength Options 6 and 7). Materials which will be freely drained during an undrained loading event will have pore water pressures specified for the drained condition and the pore water pressures will be used for both the second and third stage computations for these free—draining materials.

APPENDIX B
SUMMARY AND EXPLANATION OF PRINTED ERROR MESSAGES FOR UTEXAS3

* A *

ABOVE INTERPOLATION POINT NUMBER NOT LEGAL - REJECTED - MAX. ALLOWED = ___
The number of the interpolation points indicated on the line of data preceding this message exceeds the maximum number of points allowed by the dimensioned size of the program's arrays. Either the number of points must be reduced or the size of the program's arrays must be increased by a programmer.

ALL GRID POINTS HAD AN INDETERMINATE FACTOR OF SAFETY - SEARCH ABORTED
The factor of safety could not be computed for any of the nine points in the initial grid for the automatic search. Either the data are in error such that no valid solutions can be found or the initial estimate for the critical circle may be far from the correct location. Input data should be checked for validity and/or a new initial estimate for the critical circle should be input. If none of the solutions for the factor of safety converged, an insight into what happened may be gained by performing computations for just one selected circle (no automatic search).

* B *

BAD ARC LENGTH AND/OR SUBTENDED ANGLE FOR SUBDIVIDING CIRCLE INTO SLICES
Both the arc length and subtended angle for subdividing a circular shear surface into slices are zero or negative. One of the values must be positive. Input data for one of these variables should be changed.

BAD BASE LENGTH OR NUMBER OF INCREMENTS FOR SUBDIVIDING NONCIRCULAR SHEAR SURFACE INTO SLICES
Both the base length and number of increments for subdividing a noncircular shear surface into slices are zero or negative. One of the values must be positive. Input data for one of these variables should be changed.

BAD INITIAL INCREMENTAL DISTANCE FOR SHIFTING POINTS ON NONCIRCULAR SHEAR SURFACE DURING SEARCH - DSHIFT = ___
The incremental distance specified for shifting points in the automatic search for a critical noncircular shear surface is zero or negative. A positive, nonzero value must be input.

BAD MAXIMUM NUMBER OF ITERATIONS = ___
The maximum number of iterations specified for use in the iterative solution is either zero, negative, or exceeds 1,000. The value must range from 1 to 1,000, inclusive.

NOTE: References cited in this appendix are included in the References at the end of the main text.

BAD RADIUS FOR CIRCLE - RADIUS = ___
The information specified to designate the radius for an individual circular shear surface (no automatic search) indicates that the radius is zero or negative.

BAD REQUIRED ACCURACY (GRID SPACING) FOR LOCATING CRITICAL CENTER - ACCURACY = ___
The specified grid spacing to be used for an automatic search to locate a critical circular shear surface is zero or negative.

BAD TRIAL VALUE FOR FACTOR OF SAFETY = ___
The initial trial value which has been specified for the factor of safety is zero or negative. A positive, nonzero value must be input.

* C *

CAUTION - COMPRESSIVE FORCE IN REINFORCEMENT LINE NO. ___ AT POINT NO. ___
The program has detected a compressive force (negatively signed input value) in the reinforcement line number indicated at the point number shown. This message is printed only to alert the reader to an apparent nontypical value in the input data; however, no error has occurred and the input and results of subsequent computations may be entirely correct.

CAUTION - DATA FOR MATERIAL TYPE ___ ARE NOT USED
This message indicates that the data for the designated material are not assigned to any of the profile lines. This information is for information only and indicates that the designated material property data will not be used for the current set of profile lines.

CAUTION - DATA FOR INTERPOLATION POINT NO. ___ ARE NOT USED
This message indicates that for the designated point where data were defined for use in interpolating pore water pressures either the associated material type does not exist (there are no material property data) or pore water pressures are to be determined by means other than interpolation for the associated material. This message is for information only and indicates that the designated piezometric line data will not be used for the current set of material properties.

CAUTION - DATA FOR PIEZOMETRIC LINE NO. ___ ARE NOT USED
This message indicates that the data for the designated piezometric line are not assigned to any of the materials for which data have been input. This message is for the information only and indicates that the designated piezometric line data will not be used for the current set of material properties.

***** CAUTION ***** EFFECTIVE OR TOTAL NORMAL STRESS ON SHEAR SURFACE IS NEGATIVE AT POINTS ALONG THE UPPER ONE HALF OF THE SHEAR SURFACE - A TENSION CRACK MAY BE NEEDED
This message is printed at the end of the final output tables when the computed total or effective stress is negative along the upper one half of the shear surface. The upper one half of the shear surface is defined as the portion of the shear surface where the x coordinate lies between the cresmost

value and the average of the left-most and right-most values. This message should be self-explanatory.

***** CAUTION ***** FACTOR OF SAFETY COULD NOT BE COMPUTED FOR SOME OF GRID POINTS AROUND THE MINIMUM ***** RESULTS MAY BE ERRONEOUS *****
It was not possible to compute the factor of safety for some circular shear surfaces (prior to detecting the probable critical shear surface). The user should carefully examine why the factor of safety was not computed for the points which were shifted. If the factor of safety was not computed because a much stronger material was encountered, the results may be valid. Otherwise the results may be in error.

CAUTION - FACTOR OF SAFETY WAS NOT COMPUTED FOR SOME SHEAR SURFACES NEAR CRITICAL SURFACE - CHECK PREVIOUS OUTPUT
It was not possible to compute the factor of safety when one of the points was shifted during the last incremental shifting of the noncircular shear surface (prior to detecting the probable critical shear surface). The user should carefully examine why the factor of safety was not computed for the points which were shifted. If the factor of safety was not computed because a much stronger material was encountered, the results may be valid. Otherwise the results may be in error.

***** CAUTION ***** FORCES BETWEEN SLICES ARE NEGATIVE AT POINTS ALONG THE UPPER ONE HALF OF THE SHEAR SURFACE - A TENSION CRACK MAY BE NEEDED
This message is printed at the end of in the final output tables when the computed forces between slices are negative along the upper one half of the shear surface. The upper one half of the shear surface is defined as the portion of the shear surface where the x coordinate lies between the crest-most value and the average of the left-most and right-most values. This message should be self-explanatory.

CAUTION - INITIAL TRIAL SHEAR SURFACE IS BELOW SLOPE NEAR THE TOE OF THE SLOPE
A DISTANCE = ___
SOLUTION WILL BE ERRONEOUS IF THIS DISTANCE IS VERY LARGE
The end point coordinate of the initial trial noncircular shear surface at the toe of the shear surface is below the surface of the slope. This will cause the program to place a vertical slice boundary at the toe of the slope in the same manner that a vertical crack is modeled near the crest of the slope. The results may be erroneous. This error is printed when the shear surface end point is at a distance of 0.01 (in coordinate units, whatever they are) or more below the surface of the slope or ground. The user should attempt to reinput the coordinates of the shear surface so that they lie more precisely on the surface of the slope.

CAUTION - PORE PRESSURES SPECIFIED FOR TWO-STAGE MATERIAL NUMBER ___ PORE PRESSURES WILL BE IGNORED FOR SECOND STAGE
Pore pressures were defined for the undrained loading of the two stage analysis. This caution is for information only and indicates that the designated pore pressures will not be used for the second stage computations.

***** CAUTION ***** SOME OF THE FORCES BETWEEN SLICES ACT AT POINTS ABOVE THE SURFACE OF THE SLOPE OR BELOW THE SHEAR SURFACE - EITHER A TENSION CRACK MAY BE NEEDED OR THE SOLUTION MAY NOT BE A VALID SOLUTION
This message is printed at the end of the final output tables for Spencer's procedure when the position of the side forces (line of thrust) lies outside the limits indicated. When the line of thrust lies outside these limits near the crest of the slope, it is usually indicative of tensile stresses - a tension crack may be needed. When the line of thrust lies outside the limits of the slope and shear surface near the toe of the slope, it is often indicative of a shear surface which is excessively steep near the toe of the slope the shear surface may need to be flattened near the toe of the slope.

CAUTION - SHEAR SURFACE STEEPNESS IS WITHIN 1 DEGREE OF THE LIMITING STEEPNESS NEAR THE TOE OF THE SLOPE
The most critical shear surface located by the automatic search is within one degree of the maximum steepness permitted by the input data (or automatic default value of 50 degrees) at the toe of the slope. The search may have been restricted from examining a steeper shear surface which may have been reasonable and more critical. The user should be careful in selecting the limiting steepness. If the shear surface is allowed to become too steep, erroneous values may be computed for the factor of safety. However, the surface must be allowed to become steep enough that the most critical shear surface is detected.

CAUTION - TWO-STAGE COMPUTATIONS ARE TO BE PERFORMED, BUT THERE ARE NO MATERIALS WITH TWO-STAGE STRENGTHS - THIS MAKES NO SENSE
This message indicates that second stage computations were selected in the analysis/computation input but no two stage strengths data was input.

CAUTION - THERE WERE SURFACE PRESSURE DATA FOR THE FIRST STAGE COMPUTATIONS, BUT THERE ARE NONE FOR THE SECOND STAGE COMPUTATIONS
This message indicates that second stage computations were selected but surface pressures were not defined for the second stage analysis.

CAUTION - UNIT WEIGHT FOR MATERIAL TYPE ___ IS NEGATIVE OR ZERO
This message indicates that the designated material has been assigned zero or a negative value for the unit weight of the material. This message is for information only - a negative or zero unit weight is allowed. (A negative unit weight means that the weight forces will act upward, rather than downward).

CENTER OF CRITICAL CIRCLE COULD NOT BE FOUND AFTER TRYING ___ GRIDS IN CURRENT ARRAY - SEARCH ABORTED
The program allows a set number of grids (30) to be used in any given search "array". If this number is exceeded, this message is printed and the search is aborted. For each mode of search a new search "array" is used and in a given mode of search more than one "array" may be used. The user does not need to be concerned about how many "arrays" are actually used; the purpose of this message and "error trap" is to avoid having the search become caught in an infinite loop. The message should normally not occur. If it does, the allowed number of grids (MAXGRD) can be changed internally in the program by an experienced programmer.

CIRCLE DOES NOT INTERSECT SLOPE
The center point and radius for the circle are such that the circle does not intersect the slope.

COMPUTED SHIFT DISTANCES FOR NEWLY ESTIMATED SHEAR SURFACE FACTORED BY ___ TO PREVENT OVER-SHIFT
The computer program has estimated a new position for the trial noncircular shear surface which involves more shifting of the surface than the program allows (excessive shift distances, excessive steepness, etc.). The program has applied a uniform factor to the computed shift distances for each point and proportionately reduced the distance which they were shifted. This message may be considered a "normal" message and does not designate an error condition.

COULD NOT SOLVE SUFFICIENT EQUATIONS TO INTERPOLATE PORE WATER PRESSURES
This message is printed when none of the interpolation equations used to determine pore water pressures at the center of the base of the slice could be solved (due to ill-conditioned interpolation equations). It is only applicable and printed when the interpolation option is being used to define pore water pressures. The message is not normally expected to be issued, but if this error occurs it can probably be overcome by slightly rearranging the location of the points. The slice which triggered this error will be indicated by a previous line of information when this message occurs.

CRITICAL SHEAR SURFACE NOT LOCATED TO SPECIFIED TOLERANCES WITHIN ___ TRIES
The automatic search for a critical noncircular shear surface is permitted a preprogrammed number of attempts to locate the critical shear surface. (The number of attempts is indicated in the actual printed error message.) When the number of trials exceeds the preprogrammed number, the search is aborted and this message is printed. The user should either increase the size of the increment used to shift the noncircular shear surface in the input data or the computer program must be modified internally to permit a larger number of attempts to be used before this message is issued and the search is aborted.

* D *

DENOMINATOR IN EQUATIONS FOR FACTOR OF SAFETY WAS SMALL FOR ___ SLICES - FIRST AND LAST SLICES WHERE DENOMINATOR WAS LOW - ___ ___
A quantity which appears in the denominator of the equations used to compute the factor of safety has become small and there is a chance that an unreasonable solution may be obtained. The user should carefully examine the result for the stresses computed and printed in the final output tables for the individual slices. Ordinarily this message occurs when one of the following conditions exists: (1) There are excessive amounts of tension near the crest of the slope - a crack probably needs to be introduced, (2) Excessively high compressive stresses or various degrees of tensile stresses may exist near the toe of the slope - this unreasonable condition is likely to be indicative of a shear surface which is excessively steep near the toe of the slope, or (3) In cases where the solution for the factor of safety will not converge, the estimated value for the trial factor of safety may be excessively low - the assumed initial trial value may need to be increased.

DEPTH OF CRACK IS GREATER THAN DEPTH OF CIRCLE
The program terminates each circular shear surface at the point where the upslope (highest) end of the shear surface lies a distance equal to the specified crack depth (DCRACK) below the surface of the slope or ground. If the crack depth is greater than the greatest depth of the circle, it is impossible to terminate the end of the shear surface at a depth equal to the crack depth. Accordingly, this message will be printed.

* E *

END-OF-FILE READ WHILE ATTEMPTING TO READ PROBLEM HEADING
The program has encountered the end of the data input file while it was attempting to read a heading (Group A data).

ERROR - A BLANK LINE WAS INPUT TO DESIGNATE HOW PORE WATER PRESSURES ARE TO BE DEFINED FOR MATERIAL ___
A blank line was input with the data for the material type indicated to designate how the pore water pressures are to be defined. This error could occur if the last set of material property data were terminated with a blank line before the pore pressures have been designated.

ERROR - ABOVE POINT NO. NOT ALLOWED - REJECTED - MAX. ALLOWED = ___
This message is printed when a data point exceeds the maximum number of allowed by the program. This message will be preceeded by the data point which caused the error.

ERROR AT SLICE X = ___ Y = ___
This message is printed when an error is detected for a particular slice. The x and y coordinates are the coordinates at the center of the base of the slice. This message will be followed by a second line of information giving more details of the specific error.

ERROR AT SLICE ____ IN ASSIGNING CORPS OF ENGINEERS TYPE STRENGTHS - 2ND. STAGE EITHER R OR S STRENGTH WAS NEGATIVE
A negative shear strength value was calculated for the indicated slice in the second stage computations.

ERROR AT SLICE ____ IN ASSIGNING LOWE AND KARAFIATH TYPE STRENGTHS - 2ND. STAGE
NO DATA FOR EFFECTIVE CONSOL. STRESS RATIO
Not enough shear strength data were entered for the Lowe and Karafiath strength determination.

ERROR AT SLICE ____ IN ASSIGNING STRENGTHS FROM SINGLE ENVELOPE - 2ND. STAGE
COMPUTED UNDRAINED SHEAR STRENGTH WAS NEGATIVE
A negative shear strength value was calculated for the indicated slice in the second stage computations.

ERROR - ATTEMPTED TO STORE TOO MANY POINTS IN THE XPOINT ARRAY WHILE GENERATING THE SLOPE GEOMETRY DATA - MAX. SIZE OF ARRAY IS ___
The message is printed when the number of slope geometry data points exceeds the array size.

ERROR - BLANK LINE WAS INPUT TO DESIGNATE IF THE CIRCLE IS TO PASS THROUGH A FIXED POINT OR BE TANGENT TO A GIVEN LINE
A blank line was entered instead of the single character or character string beginning with either P (or POINT) or T (or TANGENT). This information designates how the radius of the single circle is to be defined.

ERROR - BLANK LINE WAS INPUT TO DESIGNATE THE INITIAL MODE OF SEARCH MUST INPUT ALPHA-NUMERIC CHARACTER STRING BEGINNING WITH 'P' 'T' OR 'R'

A blank line was entered instead of the single character or character string beginning with either P (or POINT), T (or TANGENT), or R (or RADIUS). This information designates how the radius of the initial circular search mode is to be defined.

ERROR - BLANK LINE WAS INPUT TO DESIGNATE THE TYPE (SHAPE) OF SHEAR SURFACE AND ANALYSIS (SEARCH/NO SEARCH) TO BE PERFORMED
A blank line was entered instead of the single character or character string beginning with either C and a blank space for Single Circular Shear Surface, C and S for Circular Search, N and a blank space for Single Noncircular Shear Surface, or N and S for Noncircular Search.

ERROR - CANNOT MODIFY SLOPE COORDINATE DATA IN MODIFY MODE - NO PREVIOUS DATA EXISTS
Slope coordinate data was not entered before attempting to modify the data. The user can only modify slope coordinate data that is entered into the program and can not modified program generated slope coordinates.

ERROR - CANNOT MODIFY SURFACE PRESSURE DATA IN MODIFY MODE - NO PREVIOUS DATA EXIST
Surface pressure data were not entered before attempting to modify the data.

ERROR - CENTER OF FIRST GRID IS BELOW CREST OF SLOPE
Y FOR GRID = ___ Y FOR CREST = ___
SEARCH ABORTED
The initial estimate for the center of the critical circle, used as a starting point for an automatic search with circular shear surfaces, lies below the crest of the slope. The crest of the slope is defined as the highest point on the slope geometry data. Although the computer program allows the center of circles to fall below the crest of the slope, the program does not allow the starting point for the search to fall below the crest of the slope. The initial estimate for the center of the critical circle needs to be modified.

ERROR COUNT LIMIT REACHED - MORE ERRORS MAY EXIST
This message indicates that the number of errors encountered while reading the data for use in interpolating pore water pressures has exceeded a preprogrammed limit in the computer program, which causes error further error checking to be abandoned. This message is designed to prevent the program from generating an excessive number of lines of output when there appears to be a major error in an extensive amount of the data. The user should correct the errors which have been printed in previous messages to this one and proceed again to execute the program with the revised data.

ERROR - END OF INITIAL TRIAL NONCIRCULAR SHEAR SURFACE AT X = ___ IS ABOVE A VERTICAL SEGMENT OF THE SLOPE
One of the end points on the initial trial noncircular shear surface lies above the slope at a point where the slope is vertical. The program is unable to adjust the end-point coordinate to bring the point back on to the slope where the end point must lie. There is probably an error in either the initial trial noncircular shear surface data or the slope geometry (or soil profile line) data.

ERROR FOR ABOVE POINT - POINT NOT PREVIOUSLY DEFINED
The user attempted to modify a data point before it was not defined.

ERROR FOR CONCENTRATED FORCE NUMBER ___
THE FORCE OPTION CODE WAS NEITHER 1 NOR 2
The option code value indicates how the concentrated force is specified. This option code must be either 1 or 2. Without a proper code value, the program can not determine how to interpret the indicated concentrated force number.

ERROR FOR DATA FOR MATERIAL TYPE ___
NOT ENOUGH ANISOTROPIC SHEAR STRENGTH DATA
The data for this material indicate that the shear strength is anisotropic, yet there are less than two points to define how the shear strength varies with the orientation of the failure plane. At least two points are required.

ERROR FOR DATA FOR MATERIAL TYPE ___
NOT ENOUGH DATA FOR PORE PRESSURE INTERPOLATION
The data for the material type indicated designated that the pore water pressures were to be determined by interpolation of values from "gridded" data. However, there were not at least 4 appropriate data points input for pore pressure interpolation. Data for at least 4 points are required for interpolation of pore pressures in each material where this option is used. Either the material property data must be revised to indicate how pore water pressures are to be determined in the material indicated, or additional data for interpolation of pore water pressures must be input.

ERROR FOR DATA FOR MATERIAL TYPE ___
NOT ENOUGH POINTS ON NONLINEAR STRENGTH ENVELOPE
The data for this material indicate that the shear strength envelope is to be nonlinear (curved) yet there are less than two points to define the shear strength envelope. At least two points are required.

ERROR FOR DATA FOR MATERIAL TYPE ___
SOMETHING IS WRONG WITH THE NEEDED PIEZOMETRIC LINE DATA - NO OR ERRONEOUS DATA FOR LINE NO. ___
The data for the material type indicated designated that the pore water pressures were to be determined from the piezometric line whose number is indicated in this message. However, there is either no data for the piezometric line or only one point was used to define the piezometric surface. At least two coordinates are required to define a piezometric line. Either the material property data need to be altered to correctly indicate how pore water pressures are to be defined for this material or the piezometric line data need to be revised/corrected.

ERROR FOR DATA FOR MATERIAL TYPE ___
SOMETHING WRONG WITH MATERIAL DATA AND/OR PORE PRESSURE INTERPOLATION POINT NO. ___
INCONSISTENCY REGARDING WHETHER PORE PRESSURE OR R-SUB-U DATA

The data for the material type indicated designated that the pore water pressures were to be determined by interpolation of values from "gridded" data. However, the material data indicated that values for interpolation were to be in terms of pressure, while the interpolation data indicate that the value for the designated material are values of the dimensionless pore pressure coefficient r-sub-u OR vice-versa. If pore pressure values are indicated in the material property input data, then the data for interpolation associated with this material must also be in terms of pore pressure (not r-sub-u), and similarly when values of the pore pressure coefficient r-sub-u are being used. Either the material property data or the pore pressure interpolation data must be revised for consistency.

ERROR FOR DATA FOR MATERIAL TYPE ___
THE FOLLOWING ANISOTROPIC STRENGTH VALUES ARE OUT-OF-ORDER
POINT ___ FAIL. PL. ORIENT. = ___
POINT ___ FAIL. PL. ORIENT. = ___

The data defining the anisotropic shear strength values for this material are not in the proper sequence. Values must be input in the sequence of increasing values for the failure plane orientation angle. The two point numbers and corresponding failure plane orientations indicated in the printed message represent the two points where the improper sequence was detected. The anisotropic shear strength data points must be corrected.

ERROR FOR DATA FOR MATERIAL TYPE ___
THE FOLLOWING POINTS FOR NONLINEAR STRENGTH ENVELOPE ARE OUT-OF-ORDER
POINT ___ SIGMA = ___ TAU ___
POINT ___ SIGMA = ___ TAU ___

The data defining the nonlinear (curved) shear strength envelope for this material are not in the proper sequence. Values must be input in the sequence of increasing values of the normal stress (SIGMA). The two point numbers and corresponding values of normal and shear stress in the printed message represent the two points where the improper sequence was detected. The points defining the nonlinear shear strength envelope must be corrected.

ERROR FOR NEW ESTIMATE OF SHEAR SURFACE
ERROR IN COMPUTING FACTOR OF SAFETY

An error has occurred in computing the factor of safety for the newly estimated trial noncircular shear surface during the automatic search. This message will be followed by additional message lines with more detailed information which should permit the user to detect the probable cause of the error. If the incremental distance used to shift the shear surface in the search is already at the minimum distance to be used, the search will be aborted when this error occurs. However, if the incremental distance used for shifting is not yet at the minimum when this error occurs, the distance used for shifting will be reduced and a new attempt will be made to find a new trial shear surface.

ERROR FOR NEW ESTIMATE OF SHEAR SURFACE
ERROR IN DETERMINING PROPERTIES FOR INDIVIDUAL SLICES
An error has occurred in determining the soil properties assigned to the individual slices for the newly estimated trial noncircular shear surface during the automatic search. This message will be followed by additional message lines with more detailed information which should permit the user to detect the probable cause of the error. If the incremental distance used to shift the shear surface in the search is already at the minimum distance to be used, the search will be aborted when this error occurs. However, if the incremental distance used for shifting is not yet at the minimum when this error occurs, the distance used for shifting will be reduced and a new attempt will be made to find a new trial shear surface.

ERROR FOR NEW ESTIMATE OF SHEAR SURFACE
ERROR IN GENERATING COORDINATES FOR SHEAR SURFACE
An error has occurred in generating the coordinates along the newly estimated trial noncircular shear surface during the automatic search. This message will be followed by additional message lines with more detailed information which should permit the user to detect the probable cause of the error. If the incremental distance used to shift the shear surface in the search is already at the minimum distance to be used, the search will be aborted when this error occurs. However, if the incremental distance used for shifting is not yet at the minimum when this error occurs, the distance used for shifting will be reduced and a new attempt will be made to find a new trial shear surface.

ERROR FOR NEW ESTIMATE OF SHEAR SURFACE
SHEAR SURFACE IS FOR OPPOSITE SLOPE FACE
The new estimate for the position of the trial noncircular shear surface lies on the opposite slope face from the initial shear surface estimated to start the search. If the incremental distance used to shift the shear surface in the search is already at the minimum distance to be used, the search will be aborted when this error occurs. However, if the incremental distance used for shifting is not yet at the minimum when this error occurs, the distance used for shifting will be reduced and a new attempt will be made to find a new trial shear surface.

ERROR FOR PIEZOMETRIC LINE NO. ___
NOT ENOUGH POINTS
Only one coordinate point has been entered to define the piezometric line indicated. At least two coordinates are required to define a piezometric line. Data for the piezometric line should be corrected.

ERROR FOR PIEZOMETRIC LINE NO. ___
POINT ON THE FOLLOWING SEGMENT ARE OUT-OF-ORDER
POINT ___ X = ___ Y = ___
POINT ___ X = ___ Y = ___
The coordinate points for the piezometric line indicated are not in the sequence of increasing x coordinate value. The two points with numbers and coordinates printed in the error message are the two points which are not in the proper order. Points must be specified in a left-to-right sequence,

although x coordinates may be repeated to define a vertical piezometric line segment.

ERROR FOR PORE PRESSURE INTERPOLATION POINT NO. ___
MATERIAL TYPE = ___ IS NOT ALLOWED
The material type indicated for the designated pore pressure interpolation data point is either zero, negative, or exceeds the maximum number of material types allowed by the dimensioned size of arrays in the computer program. The material type for the pore pressure interpolation point needs to be corrected.

ERROR FOR PROFILE LINE NO. - ___
POINTS OUT-OF-ORDER
POINT ___ X = ___ Y = ___
POINT ___ X = ___ Y = ___
The profile line coordinate points are not in the sequence of increasing x coordinate value. The two points with numbers and coordinates printed in the error message are the two points which are not in the proper order.

ERROR FOR REINFORCEMENT LINE NO. ___ Option:___ Is not a valid option
The option code value indicates how the reinforcement forces are applied to the slices in the stability computations. Only values of 1 or 2 are valid options.

ERROR FOR REINFORCEMENT LINE NO. - ___
POINTS OUT-OF-ORDER
POINT ___ X = ___ Y = ___
POINT ___ X = ___ Y = ___
The reinforcement line coordinate points are not in the sequence of increasing x coordinate value. The two points with numbers and coordinates printed in the error message are the two points which are not in the proper order.

ERROR FOR THE ABOVE POINT
LINE NO. NOT ALLOWED - MAX. ALLOWED = ___
The profile line number which has been specified for a profile line which is to be modified is either zero, negative, or exceeds the maximum number of profile lines allowed by the dimensioned capacity of the program's arrays. This message will be preceded by the line of data for the profile line which caused the error.

ERROR FOR THE ABOVE POINT
PIEZOMETRIC LINE NO. NOT ALLOWED - MAX. ALLOWED = ___
The piezometric line number which has been specified for a piezometric line which is to be modified is either zero, negative, or exceeds the maximum number of piezometric lines allowed by the dimensioned capacity of the program's arrays. This message will be preceded by the line of data for the profile line which caused the error.

ERROR FOR THE ABOVE POINT
PIEZOMETRIC LINE NOT PREVIOUSLY DEFINED
The piezometric line number specified for a piezometric line which is to be modified has not been previously defined and, thus, cannot be modified. This

message will be preceded by the line of data for the piezometric line which caused the error.

ERROR FOR THE ABOVE POINT
PIEZOMETRIC LINE POINT NOT PREVIOUSLY DEFINED
The point on the specified piezometric line which is to be modified has not been previously defined and, thus, cannot be modified. The number of the point specified is either zero, negative, or exceeds the number of points which has been previously defined for the designated piezometric line. This message will be preceded by the line of data for the piezometric line which caused the error.

ERROR FOR THE ABOVE POINT
PROFILE LINE NO. NOT ALLOWED - MAX. ALLOWED = ___
The profile line number which has been specified for a profile line which is to be modified is either zero, negative, or exceeds the maximum number of profile lines allowed by the dimensioned capacity of the program. This message will be preceded by the line of data for the profile line which caused the error.

ERROR FOR THE ABOVE POINT
PROFILE LINE NOT PREVIOUSLY DEFINED
The profile line number specified for a profile line which is to be modified has not been previously defined and, thus, cannot be modified. This message will be preceded by the line of data for the profile line which caused the error.

ERROR FOR THE ABOVE POINT
PROFILE LINE POINT NOT PREVIOUSLY DEFINED
The point on the specified profile line which is to be modified has not been previously defined and, thus, cannot be modified. The number of the point specified is either zero, negative, or exceeds the number of points which has been previously defined for the designated profile line. This message will be preceded by the line of data for the profile line which caused the error.

ERROR FOR THE ABOVE POINT
REINFORCEMENT LINE NOT PREVIOUSLY DEFINED
The reinforcement line number which has been specified has not be defined before attempting to modify. This message will be preceded by the line of data for the reinforcement line which caused the error.

ERROR FOR THE FOLLOWING SLOPE COORDINATES - POINTS OUT-OF-ORDER
POINT ___ X = ___ Y = ___
POINT ___ X = ___ Y = ___
The slope coordinate points are not in the sequence of increasing x coordinate value. The two points with numbers and coordinates printed in the error message are the two points which are not in the proper order.

ERROR FOR THE FOLLOWING SURFACE PRESSURE POINTS
POINT ___ X = ___ Y = ___
POINT ___ X = ___ Y = ___
NONZERO PRESSURE ON VERTICAL SLOPE
Surface pressures cannot be specified on a vertical slope. A vertical slope will coincide with a portion of a vertical boundary between slices and forces on all such vertical boundaries are considered to be "lumped" together in the side forces. If surface pressures must be specified on a vertical boundary, the slope should be given a very slight inclination from the vertical, such that surface pressures can be legally specified.

ERROR FOR THE FOLLOWING SURFACE PRESSURE POINTS
POINT ___ X = ___ Y = ___
POINT ___ X = ___ Y = ___
THE POINTS ARE OUT-OF-ORDER
The coordinates of the points where the surface pressures are specified are not in the sequence of increasing x coordinate value. The two points with numbers and coordinates printed in the error message are the two points which are not in the proper order.

ERROR IN COMPUTING SHIFT INVOLVING MOVING POINT A DISTANCE ___ ALONG OR PARALLEL TO SLOPE
An error has been detected when moving one of the two end points of the non-circular shear surface along the slope or parallel to the slope (in the case of a vertical crack). This message should be followed by additional message lines with further details of the error - See other error descriptions in this listing of error messages.

ERROR IN CURVED FAILURE ENVELOPE AT SLICE ___ - NORMAL STRESS = ___
NORMAL STRESS OUTSIDE RANGE OF VALUES FOR ENVELOPE
The computed normal stress on the base of the slice (slice number indicated) is either less than the lowest normal stress specified in the input data to define the nonlinear shear strength envelope or greater than the largest values specified in the input data for the envelope. The range of values used in the input data may need to be extended or, in the case where the normal stresses are tensile it may be more appropriate to introduce a vertical crack, rather than to extend the failure envelope into the range of negative (tensile) normal stresses.

ERROR IN DATA DESIGNATING IF POINTS ARE TO BE ADDED OR REPLACED THE FOLLOWING LINE OF DATA WAS INPUT -

_____
THE LINE SHOULD BE BLANK OR CONTAIN A CHARACTER STRING BEGINNING WITH THE LETTER A OR R
NOTE - TWO BLANK LINES ARE REQUIRED TO TERMINATE ALL DATA FOR PORE WATER PRESSURE INTERPOLATION
The program has attempted to read a line of data for interpolation of pore water pressures designating whether the values which are to follow are to be added to the existing data for pore pressure interpolation or are to replace existing data for pore pressure interpolation (the Modify mode of input is in effect). Either the line of data must contain a character string beginning with the letter "A" (for Add) or "R" (for Replace), or the line of input must

be blank. This error may occur when the user has intended to terminate all of the data for interpolation of pore water pressures, but has forgotten to include two blank lines following the last numerical values input.

ERROR IN DATA DESIGNATING IF PORE WATER PRESSURES OR R-SUB-U VALUES ARE TO BE INPUT - THE FOLLOWING LINE OF DATA WAS INPUT -

_____

THE LINE SHOULD BE BLANK OR CONTAIN A CHARACTER STRING BEGINNING WITH THE LETTER P OR R
NOTE - TWO BLANK LINES ARE REQUIRED TO TERMINATE ALL DATA FOR PORE WATER PRESSURE INTERPOLATION
The program has attempted to read a line of data for interpolation of pore water pressures designating whether the values which are to follow are values of pressures or the dimensionless coefficient r-sub-u. Either the line of data must contain a character string beginning with the letter "P" or "R", or the line of input must be blank. This error may occur when the user has intended to terminate all of the data for interpolation of pore water pressures, but has forgotten to include two blank lines following the last numerical values input.

ERROR IN GENERATING COORDINATES FOR CRITICAL CIRCULAR SHEAR SURFACE -

An error has been detected in the generation of the coordinates for the critical circular shear surface. This message should be followed by additional message lines with further details of the error.

ERROR IN GENERATING COORDINATES FOR SELECTED CIRCULAR SHEAR SURFACE -
An error has been detected in the generation of the coordinates for the specified circular shear surface. This message should be followed by additional message lines with further details of the error.

ERROR IN GENERATING COORDINATES FOR CRITICAL NONCIRCULAR SHEAR SURFACE -
An error has been detected in the generation of the coordinates for the critical noncircular shear surface. This message should be followed by additional message lines with further details of the error.

ERROR IN GENERATING COORDINATES FOR SELECTED NONCIRCULAR SHEAR SURFACE -
An error has been detected in the generation of the coordinates for the specified noncircular shear surface. This message should be followed by additional message lines with further details of the error.

ERROR IN LINE OF INPUT DATA
An error has been detected in the line of input data. This message should be followed by additional message lines with further details of the error. The line of input data which caused the error will precede this error message.

ERROR IN READING COMMAND WORD
An error has been detected when trying to read a command word. The line of input data which caused the error will precede this error message. This message should be followed by additional lines giving more specific detail pertaining to this error.

ERROR IN READING CONSTANT PORE PRESSURE
Some form of format related error has been encountered while the program was reading the line of data containing the value of the pore water pressure when the pore water pressures have been designated as being constant within the current material. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING CONSTANT R-SUB-U
Some form of format related error has been encountered while the program was reading the line of data containing the value of the pore pressure coefficient r-sub-u when the pore water pressures have been designated as being defined by a constant value of r-sub-u within the current material. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING COORDINATES OR POINT FOLLOWING POINT ___ ON PIEZOMETRIC LINE NO. ___
Some form of formatting error has been encountered while reading the coordinates of points on the piezometric line. The point number indicated in the above error message is the number of the point which was last read successfully. This message will be preceded by another-message giving more detail.

ERROR IN READING COORDINATES OF POINT THROUGH WHICH CIRCLE PASSES
Some form of format related error has been encountered while the program was reading the line of data containing the coordinate values through which the circular shear surface passes when the radius of the circle has been designated as being defined by a pair of X and Y coordinates along the circle. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING DATA FOR ADDING NEW POINT TOO MANY POINTS - MAX. ALLOWED = ___
The addition of the data points using the modified mode of inputexceeds the allowed maximun number of points allowed. This message will be preceded by the data point which caused the error.

ERROR IN READING DATA FOR CENTER AND RADIUS OF CIRCLE
___ VALUE(S) WAS(WERE) INPUT - ___ IS(ARE) REQUIRED THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

___

Some form of format related error has been encountered while the program was reading the line of data containing the X and Y coordinates for the center of a singular circle and the radius of the circle. The specific details pertaining to this error are provided in the last two lines of the message.

ERROR IN READING DATA FOR CONCENTRATED FORCES
Some form of format related error has been encountered while the program was reading the concentrated force data. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING DATA FOR POINTS TO BE SHIFTED
COULD NOT INTERPRET IF POINT WAS FIXED OR MOVEABLE THE FOLLOWING LINE WAS INPUT _____
THE THIRD FIELD WAS INTERPRETED AS ____
Some form of format related error has been encountered while the program was reading the data defining the initial noncircular shear surface for a search. The shift field should be either "blank" for the point to be fully movable; "numerical value" indicating the direction to shift the point; or "FIX" indicating the point will not be shifted. The specific details pertaining to this error are provided in the last two lines of the message.

ERROR IN READING DATA FOR POINTS TO BE SHIFTED
TOO MANY POINTS - MAX. ALLOWED = ___
This message is printed when the data points defining the initial noncircular shear surface exceeds the maximum number allowed by the program. This message will be preceeded by the data point which caused the error.

ERROR IN READING DATA FOR PORE PRESSURE INTERPOLATION
Some form of formatting error has been encountered while reading the data containing the x,y coordinates, pressure (or r-sub-u value) and material type for one of the data points to be used for interpolation of values of pore water pressure (or r-sub-u). This message will be preceded by another message giving more detail.

ERROR IN READING DATA FOR REPLACEMENT POINT
Some form of formatting error has been encountered while reading the data containing the point number, x and y coordinates, pressure (or r-sub-u value) and material type for one of the pore pressure interpolation data points which is being modified (the Modify mode of input is in effect). This message will be preceded by another message giving more detail.

ERROR IN READING DATA FOR STARTING COORDINATES ACCURACY, ETC. FOR SEARCH
Some form of format related error has been encountered while the program was reading the line of data containing the X and Y coordinates of the center of the initial circle for a circular search, the search grid accuracy, and the limiting Y coordinate for the searches. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING DATA TO MODIFY PIEZOMETRIC LINE COORDINATES
Some form of formatting error has been encountered while reading the data containing the line number, point number and new coordinates for a piezometric line point which is to be modified. This message will be preceded by another message giving more detail.

ERROR IN READING DATA TO MODIFY PROFILE LINE COORDINATES
Some form of formatting error has occurred while reading the data containing the line number, point number and new coordinates for a profile line point which is to be modified. This message will be preceded by another message giving more detail.

ERROR IN READING DATA TO MODIFY REINFORCEMENT LINE COORDINATES
Some form of formatting error has occurred while reading the data containing the line number, point number and new coordinates for a reinforcement line point which is to be modified. This message will be preceded by another message giving more detail.

ERROR IN READING FIRST LINE OF DATA (MATERIAL TYPE/LABEL) FOR ONE OF THE SETS OF MATERIAL DATA
Some form of formatting error has been encountered while reading the data containing the number and the label for one of the sets of material property data. This message will be preceded by another message giving more detail regarding the source of the error.

ERROR IN READING LINE OF DATA TO CHARACTERIZE TYPE OF SHEAR SURFACE AND/OR ANALYSIS
Some form of formatting error has been encountered while reading the data containing the type of shear surface and analysis (single surface or search) for one set of analysis/compuration data. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING MINIMUM THETA
ONLY ___ VALUES READ - 1 VALUE REQUIRED

ERROR IN READING MINIMUM THETA
Specified minimum theta: _____ degrees

ERROR IN READING MAXIMUM THETA
Specified maximum theta: _____ degrees

ERROR IN READING PIEZOMETRIC LINE NUMBER
Some form of format related error has been encountered while the program was reading the line of data containing the number of the piezometric line when the pore pressures have been designated as being defined by a piezometric line for the current material. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING PROFILE LINE COORDINATES
Some form of formatting error has occurred while reading the coordinates of points on the profile line. This message will be preceded by another message giving more detail.

ERROR IN READING PROFILE LINE NUMBER AND/OR MATERIAL TYPE
Some form of formatting error has occurred while reading the profile line number or material type. This message will be preceded by another message giving more detail.

ERROR IN READING REINFORCEMENT LINE COORDINATES
Some form of formatting error has occurred while reading the coordinates of points on the reinforcement line. This message will be preceded by another message giving more detail.

ERROR IN READING REINFORCEMENT LINE NUMBER
Some form of formatting error has occurred while reading the reinforcement line number. This message will be preceded by another message giving more detail.

ERROR IN READING REQUIRED ACCURACY (SHIFT DISTANCE)
Some form of formatting error has been encountered while reading the data containing the required accuracy or shift distance for a noncircular search. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING SHEAR STRENGTH DATA
Some form of formatting error has been encountered while reading a line of data containing the shear strength values for the current material. This message will be preceded by another message giving more detail.

ERROR IN READING SHEAR SURFACE COORDINATES
___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF ___ ARE REQUIRED - THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____
NOTE - BLANK LINE REQUIRED TO TERMINATE DATA
Some form of formatting error has occurred while reading the coordinates of points on the noncircular shear surface. The specific details pertaining to this error are provided in the last two lines of the message.

ERROR IN READING SHEAR SURFACE COORDINATES
TOO MANY COORDINATES - MAX. ALLOWED = ___
This message is printed when the data points defining the initial noncircular shear surface exceeds the maximum number allowed by the program. This message will be preceeded by the data point which caused the error.

ERROR IN READING SIDE FORCE INCLINATION FOR CORPS OF ENGINEERS "MODIFIED SWEDISH PROCEDURE"
Some form of formatting error has occurred while reading the side force inclination required for the modified swedish analysis procedure. This message will be preceeded by the data point which caused the error.

ERROR IN READING SIDE FORCE INCLINATION FOR MOMENT EQUILIBRIUM (ONLY) PROCEDURE
ERROR IN READING THE CONSTANT RADIUS
Some form of format related error has been encountered while the program was reading the line of data containing the constant radius value for the initial circular shear surface when the radius of the initial circular search has been designated as being defined by a constant value. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING THE NUMBER OF THE PIEZOMETRIC LINE TO BE INPUT
Some form of format related error has been encountered while the program was reading the data used to define the piezometric line. The line of data containing the number of the piezometric line (and, optionally, the unit weight of fluid for the piezometric line) contains some form of improperly formatted

data. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR IN READING UNIT WEIGHT
Some form of formatting error has occurred while reading the unit weight for the current material. This message will be preceded by another message giving more detail.

ERROR IN READING Y COORDINATE OF LINE TO WHICH CIRCLE IS TANGENT
Some form of format related error has been encountered while the program was reading the line of data containing the Y coordinate value through which the circular shear surface passes when the radius of the circle has been designated as being tangent to a specified horizontal line. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR - NO MATERIAL PROPERTY DATA
The program has been directed to perform computations by the Command Word "COMPUTE" or the Command Word "NO COMPUTE" has been entered before any material property data have been entered. Data for at least one material are required for the program to perform computations.

ERROR - NO ANALYSIS/COMPUTATION (GROUP H) DATA
The program has been directed to perform computations by the Command Word "COMPUTE" or the Command Word "NO COMPUTE" has been entered before any data have been entered for the analysis and computations.

ERROR - NO PROFILE LINE DATA
The program has been directed to perform computations by the Command Word "COMPUTE" or the Command Word "NO COMPUTE" has been entered before any profile line data have been entered. Data for at least one profile are required for the program to perform computations.

ERROR - NOT ENOUGH DATA ON LINE OF INPUT
Some form of formatting error has been encountered while reading a line of data. Not enough data were read to identified the information. This message will be preceded by another message giving more detail.

ERROR - NOT ENOUGH PROFILE LINE DATA TO GENERATE THE SLOPE GEOMETRY

ERROR - PROFILE LINE DATA ARE BAD - CANNOT GENERATE SLOPE GEOMETRY SEE LATER ERROR MESSAGES

ERROR - SEGMENT NO. ___ OF PROFILE LINE NO. ___ AND SEGMENT NO. ___ OF PROFILE LINE NO. ___ COINCIDE
Two profile lines have segments which coincide for at least a portion of their length. This is not allowed - the program cannot determine which of the two profile lines is applicable to the material below the profile line segment where the two lines coincide. Note: The order in which profile lines are numbered and input has no effect. Each profile line is treated entirely independently of the other.

ERROR - SHEAR SURFACE WAS STEEPER THAN PRESCRIBED MAXIMUM INCLINATION ALLOWED NEAR TOE AND COULD NOT BE ADJUSTED TO A FLATTER ANGLE
INPUT DATA PROBABLY NEED TO BE CHANGED
During the automatic search for a critical noncircular shear surface the inclination of the shear surface near the toe of the slope has exceeded the prescribed maximum allowable inclination and could not be adjusted by the program. Ordinarily this error will occur because the initial trial noncircular shear surface was excessively steep near the toe of the slope. Either the initial trial shear surface should be changed or the limiting (allowable) steepness should be increased. The default limiting steepness is 50 degrees and unless specifically specified otherwise by the user as part of the input data the default value will be used.

ERROR - THE MATERIAL TYPE NUMBER INPUT WAS = ___
NOT ALLOWED - MAXIMUM NUMBER ALLOWED = ___
The material type number input was either zero, negative, or exceeded the maximum number of materials allowed by the program's dimensioned size of arrays. The array size is indicated in the printed error message. Either the data need to be corrected or the size of the arrays must be increased by a programmer.

ERROR - THE PIEZOMETRIC LINE NUMBER INPUT WAS = ___
NOT ALLOWED - MAXIMUM NUMBER ALLOWED = ___
The piezometric line number input was either zero, negative, or exceeded the maximum number allowed by the dimensioned size of the program's arrays. The array size is indicated in the printed error message. Either the data need to be corrected or the size of arrays must be increased by a programmer.

ERROR - THE PROFILE LINE NUMBER INPUT WAS = ___
NOT ALLOWED - MAXIMUM NUMBER ALLOWED = ___
The profile line number input was either zero, negative, or exceeded the maximum number allowed by the dimensioned size of the program's arrays. The array size is indicated in the printed error message. Either the data need to be corrected or the size of arrays must be increased by a programmer.

ERROR - THE REINFORCEMENT LINE NUMBER INPUT WAS = ___
NOT ALLOWED - MAXIMUM NUMBER ALLOWED = ___
The reinforcement line number input was either zero, negative, or exceeded the maximum number allowed by the dimensioned size of the program's arrays. The array size is indicated in the printed error message. Either the data need to be corrected or the size of arrays must be increased by a programmer.

ERROR - THERE ARE NO MATERIAL DATA FOR FIRST-STAGE FOR MATERIAL ___
CANNOT USE SAME DATA FOR SECOND STAGE
The program has been directed to perform mulit-staged computations by the Command Word "COMPUTE" or the Command Word "NO COMPUTE" has been entered before any first stage material property data have been entered. First-stage material data are required for the program to perform multi-staged computations.

ERROR - THERE ARE NO PIEZOMETRIC LINE DATA FOR FIRST-STAGE FOR LINE ___
CANNOT USE SAME DATA FOR SECOND STAGE
The program has been directed to perform mulit-staged computations by the Command Word "COMPUTE" or the Command Word "NO COMPUTE" has been entered before any first stage piezometric line data have been entered. First-stage piezometric line data were specified in the material properties for piezometric information and are required for the program to perform multi-staged computations.

ERROR - TOO MANY PROFILE LINE POINTS - MAX. ALLOWED = ___
The number of profile line coordinate points has exceeded the capacity of the program as determined by the dimensioned size of arrays used to store the coordinate values. The maximum number of points allowed on any line is indicated in the error message. The user must either change the input data or the dimensioned size of arrays must be increased by an experienced programmer. As an alternative to increasing the dimensioned size of arrays the user may break the profile line into a number of smaller portions, each with the acceptable number of points.

ERROR - TOO MANY REINFORCEMENT LINE POINTS - MAX. ALLOWED = ___
The number of reinforcement line coordinate points has exceeded the capacity of the program as determined by the dimensioned size of arrays used to store the coordinate values. The maximum number of points allowed on any line is indicated in the error message. The user must either change the input data or the dimensioned size of arrays must be increased by an experienced programmer. As an alternative to increasing the dimensioned size of arrays the user may break the reinforcement line into a number of smaller portions, each with the acceptable number of points.

ERROR - TOO MANY SLOPE COORDINATES WERE GENERATED MAX.
ARRAY SIZE OF ___ WAS EXCEEDED
The number of slope coordinate points generated has exceeded the capacity of the program as determined by the dimensioned size of arrays used to store the coordinate values. The user must either change the input data or the dimensioned size of arrays must be increased by an experienced programmer.

ERROR - UNRECOGNIZABLE PROCEDURE FOR COMPUTING FACTOR OF SAFETY
Some form of format related error has been encountered while the program was reading the line of data containing the type of procedure to use for computation of the factor of safety. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR WAS ENCOUNTERED WHILE READING SLOPE GEOMETRY DATA
Some form of format related error has been encountered while the program was reading the slope geometry coordinate data. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR WAS ENCOUNTERED WHILE READING SURFACE PRESSURE DATA
Some form of format related error has been encountered while the program was reading the surface pressure data. This message will be preceded by another message giving more specific detail pertaining to this error.

ERROR - YOU HAVE ATTEMPTED TO DEFINE (RE-INPUT) A CONCENTRATED FORCE WHICH WAS JUST INPUT
The data for the concentrated force which was just entered were previously entered in the same batch of data following the Command Word "FORces". It does not make sense to define and then redefine concentrated force data without an intermediate set of computations. Accordingly, any attempt to do so is considered an error by the program. Data must be corrected in an appropriate manner.

ERROR - YOU HAVE ATTEMPTED TO DEFINE (RE-INPUT) A PIEZOMETRIC LINE WHICH WAS JUST DEFINED
The data for the piezometric line which was just entered were previously entered in the same batch of data following the Command Word "PIEzometric line data". It does not make sense to define and then redefine piezometric lines without an intermediate set of computations. Accordingly, any attempt to do so is considered an error by the program. Data must be corrected in an appropriate manner.

ERROR - YOU HAVE ATTEMPTED TO DEFINE (RE-INPUT) A PROFILE LINE WHICH WAS JUST DEFINED
The data for the profile line which was just entered were previously entered in the same batch of data following the Command Word "PROfile line data". It does not make sense to define and then redefine profile lines without an intermediate set of computations. Accordingly, any attempt to do so is considered an error by the program. Data must be corrected in an appropriate manner.

ERROR - YOU HAVE ATTEMPTED TO DEFINE (RE-INPUT) A REINFORCEMENT LINE WHICH WAS JUST DEFINED
The data for the reinforcement line which was just entered were previously entered in the same batch of data following the Command Word "REInforcement line data". It does not make sense to define and then redefine profile lines without an intermediate set of computations. Accordingly, any attempt to do so is considered an error by the program. Data must be corrected in an appropriate manner.

ERROR - YOU HAVE ATTEMPTED TO DEFINE (RE-INPUT) A SET OF MATERIAL PROPERTIES WHICH WAS JUST DEFINED
The data for the material properties which was just entered were previously entered in the same batch of data following the Command Word "MATerial property data". It does not make sense to define and then redefine material properties without an intermediate set of computations. Accordingly, any attempt to do so is considered an error by the program. Data must be corrected in an appropriate manner.

* F *

FACTOR OF SAFETY BECAME SMALLER THAN ___
The factor of safety has become smaller than the minimum (preprogrammed) value allowed by the computer program. The minimum value allowed is indicated in the error message.

FATAL ERROR - __________ DOES NOT EXIST FOR INPUT
The input file specified by the user does not exist in either the default directory or in the directory specified by the user.

FATAL ERROR - ALL EXECUTION TERMINATED
The program has encountered an error while attempting some calculations. Information printed on subsequent line after this message should give more details concerning the problem.

FATAL ERROR FOR INITIAL TRIAL CIRCLE FOR AUTOMATIC SEARCH
SEARCH ABORTED - See Message on Next Line(s)
The program has encountered an error while attempting to generate the coordinates along the initial trial circular shear surface which is to be used for an automatic search. Information printed on subsequent line after this message should give more details concerning the problem.

FATAL ERROR FOR INITIAL TRIAL SURFACE - SEARCH ABORTED
ERROR IN COMPUTING FACTOR OF SAFETY
An error has occurred in computing the factor of safety for the initial trial noncircular shear surface used in an automatic search. This message will be followed by additional message lines with more detailed information which should permit the user to detect the probable cause of the error.

FATAL ERROR FOR INITIAL TRIAL SURFACE - SEARCH ABORTED
ERROR IN DETERMINING PROPERTIES FOR INDIVIDUAL SLICES
An error has occurred in determining the soil properties assigned to the individual slices for the initial trial noncircular shear surface used in an automatic search. This message will be followed by additional message lines with more detailed information which should permit the user to detect the probable cause of the error.

FATAL ERROR FOR INITIAL TRIAL SURFACE - SEARCH ABORTED
ERROR IN GENERATING COORDINATES FOR SHEAR SURFACE
An error has occurred in generating the coordinates along the initial trial noncircular shear surface used in an automatic search. This message will be followed by additional message lines with more detailed information which should permit the user to detect the probable cause of the error.

FATAL ERROR FOR SLICE ___ - DENOMINATOR IN EQUATIONS FOR FACTOR OF SAFETY
BECAME SMALLER THAN ALLOWED - DENOMINATOR = ___
A quantity which appears in the denominator of the equations used to compute the factor of safety has become excessively small and there is a chance that division by a number approaching zero may occur. Accordingly, the iterative solution for the factor of safety has been aborted. Ordinarily this message occurs when one of the following conditions exists: (1) There are excessive amounts of tension near the crest of the slope - a crack probably needs to be introduced or (2) Excessively high compressive stresses or various degrees of tensile stresses may exist near the toe of the slope - this unreasonable condition is likely to be indicative of a shear surface which is excessively steep near the toe of the slope.

FATAL ERROR IN CALCULATING FACTOR OF SAFETY
An error has occured in calculating the factor of safety. This message will be followed by additional message lines with more detailed information which should permit the user to detect the probable cause of the error.

FINAL NUMBER OF SHEAR SURFACE COORDINATES EXCEEDED THE ALLOWABLE MAXIMUM
MAXIMUM NUMBER ALLOWED = ___
The combined number of noncircular shear surface coordinates (= number of slices plus one) which were specified by the input data and are required (e.g. where the shear surface crosses a profile line) has exceeded the dimensioned size of arrays. The computer program cannot eliminate coordinates specified by the input data or required by the program. Thus, this message is a fatal error which requires that the shear surface be abandoned. The user must either reduce the number of specified coordinates on the shear surface (or number of profiles lines, etc.) or the dimensioned size of arrays used to store the shear surface coordinates and information for individual slices must be increased.

FOR TRIAL NUMBER ___ WITH A NONLINEAR STRENGTH ENVELOPE
THE MAXIMUM PERCENT CHANGE IN SHEAR STRENGTH WAS ___ - AT SLICE ___
An iterative procedure is used to arrive at the shear strengths using a non-linear shear strength envelope: A shear strength is estimated, the factor of safety and corresponding normal stresses on the shear surface (base of slices) are calculated, and a new estimate of the shear strength is made. This message is printed after each iteration in which the shear strength is adjusted (actually on each "iteration" there are also several iterations to compute the factor of safety for the given estimate of the shear strength). This message indicates the number of the trial, the maximum percent change in shear strength (based on an examination of the changes for all slices) and the number of the slice where the maximum change occurred. The "percent change" is computed by taking the difference between the shear strength assumed and the new shear strength computed (using in both cases the normal stress calculated with the assumed shear strength) and dividing the difference by the largest of the two shear strength values (assumed and new estimate).

* I *

ILLEGAL MATERIAL TYPE FOR PROFILE LINE ___ - MATERIAL TYPE = ___
The material type specified in the input data for the designated profile line is zero, negative, or exceeds the maximum number of materials allowed.

ILLEGAL PROCEDURE FOR COMPUTING FACTOR OF SAFETY
PROCEDURE NOT ALLOWED FOR NONCIRCULAR SHEAR SURFACES
The procedure which has been selected for computing the factor of safety (Simplified Bishop) is not applicable to noncircular shear surfaces. Noncircular shear surfaces have been specified for this procedure. Either the procedure must be changed or circular shear surfaces must be used.

ILLEGAL VALUES FOR ALLOWED FORCE AND/OR MOMENT IMBALANCE - RESPECTIVE VALUES = ___
The specified value of either (or both) the allowable force imbalance is (are) zero or negative. Both the values must be positive, nonzero quantities.

INSUFFICIENT ENVELOPES - NONE FOR F-INVERSE = _____

INSUFFICIENT PIEZOMETRIC LINE DATA - PIEZOMETRIC LINE NO. ___
This message indicates that the piezometric line data does not extend far enough laterally to include the base of a particular slice. The base of the slice has been detected to lie in a material where pore water pressures are to be determined from a piezometric line, but the data are insufficient. The piezometric line data need to be extended to cover this slice. The slice which triggered this error will be indicated by a previous line of information when this message occurs.

IRRECONCILABLE DIFFERENCES IN STRENGTHS - MATERIALS: _____, _____

* M *

MATERIAL TYPES FOR STAGES 1 AND 2 COULD NOT BE RECONCILED
MATERIAL TYPE FOR STAGE 1: _____
MATERIAL TYPE FOR STAGE 2: _____

* N *

NEGATIVE CRACK DEPTH NOT ALLOWED
A negative value has been detected for the depth of vertical crack to be used with a circular shear surface. The crack depth must be zero or positive.

NEGATIVE DEPTH FOR FLUID IN CRACK IS NOT ALLOWED
The specified depth for the fluid in the vertical crack is negative. The depth of fluid must be either zero or positive.

NEGATIVE UNIT WEIGHT FOR FLUID IN CRACK IS NOT ALLOWED
The specified unit weight for the fluid in a vertical crack is negative. The unit weight of fluid must be either zero or positive.

NO ANISOTROPIC STRENGTH DATA FOR FAILURE PLANE ANGLE OF ___ DEGREES
This message indicates that the inclination of the base of a slice, which corresponds to a "failure plane inclination," falls outside the range of values for which anisotropic shear strength values have been input. The computer program will not extrapolate values. The user should input values for a wider range of failure plane inclinations to overcome this error. The slice which triggered this error will be indicated by a previous line of information when this message occurs.

NO DATA FOR MATERIAL TYPE ___ FOR PROFILE LINE NO. ___
No material property data were input for the material type indicated. The material type indicated has been designated as the material type for the profile line whose number is given in this error message. Either the wrong material type has been input for the designated profile line or material data have been improperly omitted from the input data.

NO NONLINEAR 2-STAGE STRENGTH ENVELOPE FOR NORMAL STRESS OF ___ DEGREES
This message indicates that the normal stress on the base of a slice for the second-stage computations falls outside the range of values for which

nonlinear shear strength values have been input. The computer program will not extrapolate values. The user should input values for a wider range of normal stress values to overcome this error. The slice which triggered this error will be indicated by a previous line of information when this message occurs.

NO NUMERICAL VALUE INPUT FOR NUMBER OF THE PIEZOMETRIC LINE TO BE USED
The program did not detect a leading numerical value on the line of input data where the number of the piezometric line to be used for this material was expected (for the case where the pore pressures for the current material have been designated as being defined by a piezometric line). Something is wrong with the data if the piezometric line number or the piezometric line number has been omitted from the data for the current material. This message could occur if the pore pressures for the last (final) set of material data are specified as being defined by a piezometric line and, then, the data are terminated by a blank line before the value of the pore water pressure has been entered.

NO NUMERICAL VALUE INPUT FOR PORE PRESSURE
The program did not detect a leading numerical value on the line of input data where the value of the pore water pressure was expected (for the case where the pore pressures for the current material have been designated as being defined by a constant value of pressure). Something is wrong with the data if the pore pressure or the pore pressure has been omitted from the data for the current material. This message could occur if the pore pressures for the last (final) set of material data are specified as being constant and, then, the data are terminated by a blank line before the value of the pore water pressure has been entered.

NO NUMERICAL VALUE INPUT FOR R-SUB-U
The program did not detect a leading numerical value on the line of input data where the value of the pore pressure coefficient was expected (for the case where the pore pressures for the current material have been designated as being defined by a constant value of the pore pressure coefficient, r-sub-u). Something is wrong with the data for the pore pressure coefficient or the pore pressure coefficient has been omitted from the data for the current material. This message could occur if the pore pressures for the last (final) set of material data have been specified as being defined by a constant value of the pore pressure coefficient and, then, the data have been terminated by a blank line before the value of the pore pressure coefficient has been entered.

NO NUMERICAL VALUE INPUT FOR UNIT WEIGHT
The program did not detect a leading numerical value on the line of input data where the unit weight of the material was expected. Something is wrong with the data for the unit weight or the unit weight to be omitted from the data for the current material.

NO NUMERICAL VALUE INPUT - ONE VALUE IS REQUIRED
The program did not detect a numerical value on the line of input data where one numerical value was required. Something is wrong with the data.

NO NUMERICAL VALUE INPUT TO DESIGNATE THE NUMBER OF THE PIEZOMETRIC LINE WHICH IS BEING (TO BE) DEFINED
0 VALUE(S) WAS/WERE INPUT - 1 IS/ARE REQUIRED
THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

______

NOTE - TWO BLANK LINES REQUIRED TO TERMINATE ALL PIEZOMETRIC LINE DATA
The program did not detect a numerical value on the line of input data where the number of the piezometric line was expected. There is some error in the input data used to define the individual piezometric lines. This error could occur if the sets of coordinates for the last piezometric line defined are not terminated by two blank lines before resuming with Command Words.

NO PREVIOUS DATA EXIST FOR THIS POINT
Attempts were made to modify information about a data point for which no previous data existed. This message will be preceded by another message giving more specific detail pertaining to this message.

NO PROFILE DATA FOR SLICE
No profile lines were found to exist for any of the portion of the slice above the base of the slice. (The slice which triggered this error will be indicated by a previous line of information when this message occurs.)

NO PROFILE DATA FOR TOP OF SLICE
There are no profile lines crossing some upper portion of the slice. (The slice which triggered this error will be indicated by a previous line of information when this message occurs). It is possible that this message may be printed due to roundoff error where the program computes that the top of the slice is a very small distance above the uppermost profile line. This may indicate that one of the tolerances in the program used to "trap" round-off errors needs to be adjusted for the particular computer system being used. Care should be used in adjusting such tolerances or other errors may be introduced.

NONCIRCULAR SHEAR SURFACE POINT ___ IS OUTSIDE SLOPE LIMITS
A noncircular shear surface point is located outside the slope limits. This could occur when specifing a singular shear surface or during a noncircular search. The point which triggered this error will be indicated by a previous line of information when this message occurs.

NOT ENOUGH NUMERICAL VALUES FOR COHESION AND FRICTION ANGLE
The program has attempted to read a cohesion value and friction angle for a material with the shear strength defined in the "conventional" manner and encountered less than two numerical values on the line of input data. Two numerical values are required on the line of input data for "conventional" shear strength characterization.

NOT ENOUGH NUMERICAL VALUES INPUT FOR LINE OF ANISOTROPIC SHEAR STRENGTH DATA
___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF 3 ARE REQUIRED
THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

______

The line of input data defining the variation in shear strength with the orientation of the failure plane did not contain an even multiple of three values

for failure plane orientation and strength parameters. This error may be encountered when the user has intended to terminate the anisotropic shear strength values, but has omitted the blank line to terminate the values.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE COORDINATES OR A POINT ON THE PIEZOMETRIC LINE
___ VALUES(S) WAS/WERE INPUT ___ EVEN MULTIPLES OF 2 ARE REQUIRED THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____
NOTE - BLANK LINE REQUIRED TO TERMINATE DATA
The line of input data defining the coordinates of points along the piezometric line did not contain an even multiple of two values, representing pairs of x,y values. This error may be encountered when the user has intended to terminate the coordinates for a given profile line, but has omitted the blank line required to terminate the data.

NOT ENOUGH NUMERICAL VALUES INPUT TO DEFINE COORDINATES OF SLOPE POINT
___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF 2 ARE REQUIRED - THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____
NOTE - BLANK LINE REQUIRED TO TERMINATE DATA
The line of input data defining the coordinates of points along the slope did not contain an even multiple of two values, representing pairs of x,y values. This error may be encountered when the user has intended to terminate the coordinates for the slope geometry, but has omitted the blank line required to terminate the data.

NOT ENOUGH NUMERICAL VALUES INPUT TO DEFINE INTERPOLATION POINT
___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF 4 ARE REQUIRED
THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____
NOTE - A BLANK LINE IS REQUIRED TO TERMINATE THE CURRENT SERIES OF INTERPOLATION DATA
NOTE - TWO BLANK LINES ARE REQUIRED TO TERMINATE ALL DATA FOR PORE WATER PRESSURE INTERPOLATION
The line of input data containing the data points to be used for interpolation of values of either pore water pressure or r-sub-u line did not contain an even multiple of four values (x,y coordinates, pressure or r-sub-u value, and material type). This error may be encountered when the user has intended to terminate the interpolation data, but has omitted the necessary blank line or lines.

NOT ENOUGH NUMERICAL VALUES INPUT TO DEFINE LINEAR VARIATION IN STRENGTH WITH DEPTH BELOW GIVEN REFERENCE ELEVATION
The program has attempted to read the value of the shear strength at a designated reference elevation, the value of the reference elevation, and the rate at which the shear strength increases with depth below the reference elevation for the current material. Less than three numerical values were encountered on the line of input data; at least three numerical values must be contained on a single line of the input data.

NOT ENOUGH NUMERICAL VALUES INPUT TO DEFINE LINEAR VARIATION IN STRENGTH WITH DEPTH BELOW PROFILE LINE

The program has attempted to read the value of the shear strength along the profile line and the rate at which the shear strength increases with depth below the profile line for the current material. Less than two numerical values were encountered on the line of input data; at least two numerical values must be contained on a single line of the input data.

NOT ENOUGH NUMERICAL VALUES INPUT TO DEFINE CONCENTRATED FORCE
___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF ___ ARE REQUIRED -
THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____
NOTE - A BLANK LINE IS REQUIRED TO TERMINATE THE CONCENTRATED FORCE DATA

The line of input data for coordinates on the current concentrated force data did not contain an even multiple of six values are required to define the location and magnitude of a concentrated force. This error may be encountered when the user has intended to terminate the concentrated force data, but has omitted the blank line.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE COORDINATES OF THE CURRENT REINFORCEMENT LINE POINT ___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF ___ ARE REQUIRED - THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____
NOTE - BLANK LINE REQUIRED TO TERMINATE DATA

The line of input data for coordinates on the current reinforcement line did not contain an even multiple of four values for coordinates and reinforcement load. This error may be encountered when the user has intended to terminate the reinforcement line coordinates, but has omitted the blank line.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE COORDINATES OF THE CURRENT PROFILE LINE POINT ___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF 2 ARE REQUIRED THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____
NOTE - BLANK LINE REQUIRED TO TERMINATE DATA

The line of input data for coordinates on the current profile line did not contain an even multiple of two values for coordinates. This error may be encountered when the user has intended to terminate the profile line coordinates, but has omitted the blank line to terminate the data for the given profile line.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE THE CURRENT POINT ON THE NONLINEAR SHEAR STRENGTH ENVELOPE ___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF 2 ARE REQUIRED - THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____
The line of input data defining the points on a nonlinear (curved) shear strength envelope did not contain an even multiple of two values. This error may be encountered when the user has intended to terminate the values defining the nonlinear shear strength envelope, but has omitted the blank line to terminate the values.

NOT ENOUGH NUMERICAL VALUES INPUT TO DEFINE R AND S ENVELOPES
The program has attempted to read the values of the second-stage shear strength envelopes. Less than four numerical values were encountered on the line of input data; at least four numerical values must be contained on a single line of the input data.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE THE CURRENT POINT ON THE NONLINEAR ENVELOPES FOR TWO-STAGE STRENGTHS
The line of input data defining the points on a second-stage nonlinear (curved) shear strength envelope did not contain an even multiple of three values. This error may be encountered when the user has intended to terminate the values defining the nonlinear shear strength envelope, but has omitted the blank line to terminate the values.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE THE PROFILE LINE NUMBER AND MATERIAL TYPE ___ VALUE(S) WAS/WERE INPUT - 2 IS/ARE REQUIRED
THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____

NOTE - TWO BLANK LINES REQUIRED TO TERMINATE ALL PROFILE LINE DATA
The line of input data to define the number of the profile line and associated material type (Group B data) did not contain a pair of numerical values. Two numerical values are required; the first for the profile line number, the second for the material type. This error may be encountered when the user has intended to terminate the profile line data and return to input of Command Words, but has omitted the two blank lines to terminate all profile line data.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE SLOPE POINT WHICH IS TO BE REPLACED OR REDEFINED IN MODIFY MODE
The line of input data to modify the coordinates of a point or points on the slope geometry line did not contain a suitable number of quantities. This error may be encountered when the user has intended to terminate the data modifying slope geometry line coordinates, but has omitted the blank line which terminates the data in Modify Mode.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE SURFACE PRESSURES AT THE CURRENT COORDINATE POINT ___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF ___ ARE REQUIRED THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____

NOTE - BLANK LINE REQUIRED TO TERMINATE DATA
The program has attempted to read the surface pressure data; however, the line of input data did not contain a suitable number of numerical quantities. This error may be encountered when the user intended to terminate the reinforcement line data and return to reading Command Words, but has omitted a blank line at the end of the material property data.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE SURFACE PRESSURES IN MODIFY MODE
The line of input data to modify the coordinates of a point or points of the surface pressure data did not contain a suitable number of quantities. This error may be encountered when the user has intended to terminate the data modifying profile line coordinates, but has omitted the blank line which terminates the data in Modify Mode.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO IDENTIFY THE MATERIAL TYPE CURRENTLY BEING DEFINED ___ VALUE(S) WAS/WERE INPUT - 1 IS/ARE REQUIRED
THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____

NOTE - BLANK LINE REQUIRED TO TERMINATE DATA
The program was attempting to read the number of the material type for a set of material property data; however, the line of input data did not contain a leading numerical value. The material type is apparently missing from a line of input data. This error may be encountered when the user intended to terminate the material property data and return to reading Command Words, but has omitted a blank line at the end of the material property data.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO MODIFY THE COORDINATES OF THE CURRENT PROFILE LINE POINT ___ VALUE(S) WAS/WERE INPUT - EVEN MULTIPLES OF 4 ARE REQUIRED THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____

NOTE - BLANK LINE REQUIRED TO TERMINATE DATA
The line of input data to modify the coordinates of a point or points on profile lines did not contain a suitable number of quantities. This error may be encountered when the user has intended to terminate the data modifying profile line coordinates, but has omitted the blank line which terminates the data in Modify Mode.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO DEFINE THE REINFORCEMENT LINE NUMBER ___ VALUE(S) WAS/WERE INPUT -___ IS/ARE REQUIRED
THE ERROR WAS DETECTED FOR THE FOLLOWING LINE OF INPUT

____

NOTE - TWO BLANK LINES REQUIRED TO TERMINATE ALL REINFORCEMENT LINE DATA
The program was attempting to read the number of the reinforcement line for a set of reinforcement data; however, the line of input data did not contain a suitable number of numerical quantities. This error may be encountered when the user intended to terminate the reinforcement line data and return to reading Command Words, but has omitted a blank line at the end of the material property data.

NOT ENOUGH NUMERICAL VALUES WERE INPUT TO MODIFY THE COORDINATES OF THE CURRENT REINFORCEMENT LINE POINT
The line of input data to modify the coordinates of a point or points on reinforcement lines did not contain a suitable number of quantities. This error may be encountered when the user has intended to terminate the data modifying reinforcement line coordinates, but has omitted the blank line which terminates the data in Modify Mode.

NOTICE - Concentrated force no. ___ NOT ASSIGNED to any slice
A concentrated force is located outside the shear surface and not considered in the analysis computations. This warning is to alert the user to verify the concentrated force location.

NOT ENOUGH (OR NO) SLOPE DATA
There is no slope data. Probably only one data point was entered to define the slope geometry, otherwise the program would have automatically generated data from the profile line data.

NOT ENOUGH POINTS FOR NONCIRCULAR SHEAR SURFACE
The number of points on either an individually selected noncircular shear surface or the initial trial noncircular shear surface for an automatic search is less than two. At least two coordinate points are required to define a noncircular shear surface. Additional data points should be added to the input data.

NOT ENOUGH POINTS FOR PROFILE LINE NO. ___ - NO. OF POINTS = ___
Only one point has been entered for the profile line indicated. At least two coordinate points are required to define a profile line.

NOT ENOUGH POINTS FOR REINFORCEMENT LINE NO. ___ - NO. OF POINTS = ___
Only one point has been entered for the reinforcement line indicated. At least two coordinate points are required to define a reinforcement line.

NOT ENOUGH POINTS TO INTERPOLATE FOR PORE PRESSURE
The program could not find one point in at least three of the four quadrants surrounding the point on the center of the base of the slice where pore water pressures are being determined by interpolation. Additional points may need to be added to the interpolation data, especially along the boundaries (edges) of zones where pore water pressures are to be determined by interpolation. (Note: Points can actually lie outside the material in which they are being used for interpolation.) The slice which triggered this error will be indicated by a previous line of information when this message occurs.

NOT ENOUGH SURFACE PRESSURE POINTS
Only one point has been entered to define the surface pressures on the slope. Surface pressures must be defined at at least two coordinate points.

NUMBER OF REQUIRED SHEAR SURFACE COORDINATES EXCEEDED THE ALLOWABLE STORAGE CAPACITY OF ARRAYS (X AND Y) - MAX. ALLOWED = ___
In generating the coordinates for a circular shear surface the program computes, stores, and discards duplicates of coordinates of points on the shear surface which are required, e.g. where the shear surface intersects the profile lines. This message is printed when the number of points stored exceeds the dimensioned capacity of the program for the total number of points on a shear surface (= maximum number of slices minus one). The size of the arrays used to store shear surface coordinates, as well as a variety of other information for individual slices, needs to be changed.

NUMBER OF REQUIRED SHEAR SURFACE COORDINATES EXCEEDED THE DIMENSIONED SIZE OF ARRAYS (XSTORD AND YSTORD) IN SUBROUTINE ISTORC - DIMENSIONED SIZE = ___
In generating the coordinates for a shear surface the program computes and stores, on a temporary basis, coordinates of points on the shear surface which are required, e.g. where the shear surface intersects the profile lines (the computed points which are stored may include some duplicates); the coordinates which were specified in the input data are added to the required coordinates and stored in the temporary storage arrays. This message is printed when the number of required shear surface points exceeds the dimensioned size of the temporary storage arrays XSTORD and YSTORD. The size of the temporary storage arrays (XSTORD and YSTORD) needs to be increased in the computer program.

NUMBER OF REQUIRED PLUS SPECIFIED SHEAR SURFACE COORDINATES STORED ON A TEMPORARY BASIS EXCEEDED THE ALLOWABLE STORAGE CAPACITY - MAX. ALLOWED = ___
In generating the coordinates for a shear surface the program computes and stores, on a temporary basis, coordinates of points on the shear surface which are required, e.g. where the shear surface intersects the profile lines (the computed points which are stored may include some duplicates); the coordinates which were specified in the input data are added to the required coordinates and stored in the temporary storage arrays. This message is printed when the number of points stored exceeds the dimensioned size of the temporary storage arrays. The size of the temporary storage arrays (XSTORD and YSTORD) needs to be increased in the computer program.

NUMBER OF REQUIRED SHEAR SURFACE COORDINATES STORED ON A TEMPORARY BASIS EXCEEDED THE ALLOWABLE STORAGE CAPACITY - MAX. ALLOWED = ___
In generating the coordinates for a shear surface the program computes and stores, on a temporary basis, coordinates of points on the shear surface which are required, e. g. where the shear surface intersects the profile lines (The computed points which are stored may include some duplicates). This message is printed when the number of points stored exceeds the dimensioned size of the temporary storage arrays. The size of the temporary storage arrays (XSTORD and YSTORD) needs to be increased in the computer program.

* O *

ONLY ONE SLICE GENERATED - CIRCLE REJECTED
The specified (or default) value of either the subtended angle or slice arc length used to subdivide the circular shear surface into slices was sufficiently large that only one slice was generated. Either the values of the parameters which control the slice generation should be altered to increase the number of slices generated or the circle is one that just barely intersects the slope and is of no interest to the user. The user should ascertain if this message (error?) is of practical significance for the problem being solved.

Opposite slope face - CIRCLE REJECTED
This message is printed for a given trial circle attempted during an automatic search when the circle falls on the opposite slope face from the circle which was specified in the input data as the initial trial circle. The program does not permit the automatic search to "jump" from one slope face to another.

* S *

SHEAR SURFACE COORDINATE AT X = ___ AND Y = ___ WAS SHIFTED BEYOND LIMITS OF THE SLOPE
During the automatic search with noncircular shear surfaces the program has attempted to shift one of the end points on the shear surface beyond the end points of the lines defining the slope geometry. The data defining the slope geometry probably need to be extended further. The x and y coordinates of the shear surface point which was being shifted are printed with this message.

SHEAR SURFACE IS ON OPPOSITE SLOPE FACE - REJECTED
During an automatic search for a critical noncircular shear surface a trial shear surface has fallen on the opposite slope face from the slope face for which the search was initiated. The program does not permit the search to "jump" slope faces from the one for which the search was initiated. If the opposite face is to be analyzed, a search should be initiated with an initial trial noncircular shear surface on the opposite slope face.

SHEAR SURFACE SEGMENT BETWEEN POINTS ___ and ___ CROSSES SLOPE BETWEEN POINTS __ AND ___ AFTER SHIFT - THIS TRIAL SHEAR SURFACE WAS REJECTED
As indicated, when a point on the shear surface was temporarily shifted, the point resulted in a segment of the shear surface intersecting a segment of the lines defining the slope geometry. The temporary shift was not used - this message normally does not result in an error in the final solution unless it occurs on the final shifting, just prior to locating the critical shear surface. If the error occurs on the final shifting, another shear surface configuration of direction for shifting some points may be needed to find the most critical shear surface.

SOLUTION FOR FACTOR OF SAFETY DID NOT CONVERGE WITHIN ___ ITERATIONS
The iterative solution for the factor of safety did not converge within the prescribed maximum number of iterations allowed. The user may need to increase the allowable number of iterations. Convergence is sometimes improved by overestimating the value of the factor of safety rather than underestimating the value. Convergence problems are sometimes caused when (1) there is excessive tension near the crest of the slope (a vertical crack may need to be introduced) and (2) when the shear surface is excessively steep near the toe of the slope (the shear surface inclination should approach that expected for a critical "passive" wedge as determined by earth pressure theories).

SOMETHING IS WRONG IN DO LOOP 260 IN SUBROUTINE INTERP
This error message should never be printed. It indicates that the program has become confused while interpolating pore water pressures at the base of a particular slice. The program cannot determine in which quadrant an interpolation point lies. The user should contact S. G. Wright if this message ever occurs. The slice which triggered this error will be indicated by a previous line of information when this message occurs.

SOMETHING IS WRONG WITH A SMALL TOLERANCE CHECK IN CALCFS
QI = ___ SMALLQ = ___
MCENTB = ___ SMALLM = ___
One of the error tolerances which is computed by the program and used to check to avoid division by zero is inconsistent with other numerical values. This error occurs in the iterative solution for the factor of safety using Spencer's procedure - the user should contact S. G. Wright for remedy if this problem and message occurs. This error message should not ordinarily be printed.

SOMETHING IS WRONG WITH THE INPUT FILE NAME
The specified input file can not be located or opened by the program.

SOMETHING IS WRONG WITH RADII IN SUBROUTINE SERCH1 BETWEEN STATEMENTS 640 and 700

This error message should never be printed. The program has become confused or obtained erroneous results pertaining to the radius of the critical circle. The user should contact S. G. Wright if this error occurs.

SPECIFIED INPUT FOR MAX. SLICE BASE LENGTH AND SLICE SUBDIVISION RESULTED IN MORE THAN ___ COORDINATES - MAX. SLICE BASE LENGTH RESET TO ___

Either the maximum slice base length or approximate maximum number of slices used for subdivision of the noncircular shear surface into slices resulted in more slices than the program was capable of accommodating by the dimensioned size of arrays. Accordingly, either the maximum slice base length was successively doubled or the approximate maximum number of slices was reduced by a factor of two until a sufficiently small enough number of shear surface coordinates (slices) was generated by the program. This message is for the user's information and does not indicate that an error condition has occurred.

SPECIFIED SUBTENDED ANGLE /OR/ SLICE ARC LENGTH RESULTED IN MORE THAN ___ SLICES - SUBTENDED ANGLE RESET TO ___ DEGREES

Either the subtended angle or arc length used for subdivision of the circular shear surface into slices resulted in more slices than the program was capable of accommodating by the dimensioned size of arrays. Accordingly, either the subtended angle or slice arc length was successively doubled until a sufficiently small enough number of shear surface coordinates (slices) was generated by the program. This message is for the user's information and does not indicate that an error condition has occurred.

STRENGTHS WITH CURVED FAILURE ENVELOPE DID NOT CONVERGE IN _____ TRIALS - MAXIMUM
PERCENT CHANGE ON LAST TRIAL = ______ - MAX. ALLOWED = ______

SURFACE PRESSURE COORDINATES DO NOT COINCIDE WITH SLOPE

The program has determined that the coordinates used to define the surface pressures acting on the slope do not coincide with the slope geometry data (as defined by slope geometry input data or computed by the program from the profile line data). This error may result from input of a new set of profile line data without a new set of slope geometry data - once the program has computed or read a set of slope geometry data, the data are not changed until specifically directed by the user by (1) new slope geometry data, (2) a set of "null" slope geometry data as described in the User's Manual, or (3) by separating data sets by the Command Word "***". The slice which triggered this error will be indicated by a previous line of information when this message occurs.

* T *

THE FOLLOWING PAIR OF NONCIRCULAR SHEAR SURFACE POINTS DEFINE A VERTICAL SEGMENT OR ARE OUT-OF-ORDER
POINT ___ X = ___ Y = ___
POINT ___ X = ___ Y = ___

The coordinate points which define an individually selected noncircular shear surface or the initial trial noncircular shear surface for an automatic search

are not in the proper sequence of increasing x coordinate value. The two points whose numbers and coordinates are printed in the error message are the two points which are not in the proper order. Vertical segments are not allowed for the shear surface.

THE FOLLOWING POINTS FOR NONLINEAR STRENGTH ENVELOPE ARE OUT-OF-ORDER
POINT _____ SIGMA-FC = _____ TAU-FF(R) = _____ TAU-FF(S) = _____
POINT _____ SIGMA-FC = _____ TAU-FF(R) = _____ TAU-FF(S) = _____
The points defining a nonlinear strength envelope are not in the proper sequence of increasing "SIGMA-FC" value. The two points whose numbers and coordinates are printed in the error message are the two points which are not in the proper order.

THE POINTS ARE OUT-OF-ORDER
A set of coordinate points is not in the proper sequence of increasing x coordinate value. The two points whose numbers and coordinates are printed in the error message following this message are the two points which are not in the proper order.

THE PROGRAM WAS ATTEMPTING TO READ A COMMAND WORD AND ENCOUNTERED AN UNRECOGNIZABLE CHARACTER STRING FOR THE COMMAND WORD
THE LINE OF INPUT = __________
FIRST THREE CHARACTERS INTERPRETED AS "___"
The program was expecting to and has attempted to read a Command Word; however, the line of input encountered could not be interpreted as one of the acceptable Command Words. A Command Word may have been misspelled. Also, input data in one of the "Groups", e.g. profile lines, may have been terminated prematurely (perhaps by an extra blank line), causing the program to return to reading Command Words. An extraneous blank line at the end of all input data will also cause this error message to be printed. The message prints the entire content of the line of input which caused this error as well as the three "Command Word" characters which the program interpreted from the line of input data.

THERE WAS AN ERROR IN READING A NUMERICAL VALUE FROM THE LINE OF INPUT SHOWN BELOW _____
THE ERROR WAS ENCOUNTERED WHILE READING VARIABLE NUMBER ___ ON THIS LINE OF INPUT - A NUMERICAL VALUE WAS EXPECTED BECAUSE THE LEADING CHARACTER WAS ___
Some form of format error has been encountered while the program was reading the indicated line of input. The last two lines of this error identify the variable which caused the problem.

TOO MANY POINTS FOR ANISOTROPIC STRENGTHS - MAX. ALLOWED = ___
The number of data points selected and entered to define the variation in shear strength with failure plane orientation for an anisotropic material has exceeded the maximum number allowed by the dimensioned size of the program's arrays. Either the number of data points must be reduced or the size of arrays must be increased by a programmer.

TOO MANY POINTS FOR NONLINEAR ENVELOPE - MAX. ALLOWED = ___
The number of data points selected and entered to define nonlinear (curved) failure envelope has exceeded the maximum number allowed by the dimensioned

size of the program's arrays. Either the number of data points must be reduced or the size of arrays must be increased by a programmer.

TOO MANY POINTS FOR PIEZOMETRIC LINE NO. ___ - MAX. ALLOWED = ___
The number of data points selected and entered to define the piezometric line (number indicated in the error message) has exceeded the maximum number allowed by the dimensioned size of the program's arrays. Either the number of data points must be reduced or the size of arrays must be increased by a programmer. Note: If the number of points required to define a piezometric line exceeds the number allowed by the dimensioned size of the arrays, it may be possible to split the piezometric line into two separate lines, with the number of points on each line not exceeding the designated maximum; this may also require splitting the material/profile lines into two parts, each part being associated with an appropriate piezometric line.

TOO MANY POINTS FOR TWO-STAGE NONLINEAR ENVELOPE - MAX. ALLOWED = ___
The number of data points selected and entered to define the second-stage nonlinear (curved) failure envelope has exceeded the maximum number allowed by the dimensioned size of the program's arrays. Either the number of data points must be reduced or the size of arrays must be increased by a programmer.

TOO MANY PROFILE LINES CROSS SLICE - MAX. ALLOWED = ___
This message is printed when the number of profile lines which cross a particular slices exceed the dimensioned capacity of arrays ISTORD and YSTORD in Subroutine SLICES - the number of profile lines must be reduced or the dimensioned size of the arrays ISTORD and YSTORD must be increased. (The slice which triggered this error will be indicated by a previous line of information when this message occurs.)

TWO-STAGE STRENGTHS WERE SPECIFIED FOR THE FIRST STAGE - THIS IS NOT ALLOWED
One of the two second-stage strengths desingations were used to describe how the first stage strength was to be characterized. Only one of the first five strength designations can be used for the first stage strength.

* U *

UNRECOGNIZABLE CHARACTERS WERE INPUT TO DESIGNATE HOW THE PORE WATER PRESSURES ARE TO BE DEFINED FOR MATERIAL ___
INPUT LINE = _____
The first two character strings which were read as input to designate how the pore water pressures are to be defined for the material indicated did not start with one of the acceptable character pairs: C P (for Constant Pore pressure), C R (for Constant R-sub-u), N (- one character only - for No pore pressures/total stresses), I P (for Interpolation of Pore pressure values), or I R (for Interpolation of R-sub-u values).

UNRECOGNIZABLE CHARACTERS WERE INPUT TO DESIGNATE HOW THE SHEAR STRENGTH IS TO BE DEFINED FOR MATERIAL ___
INPUT LINE = _____
The character string which was read as input to designate how the shear strength was to be defined for the material indicated did not start with one

of the acceptable characters: A (for Anisotropic), C (for Conventional), I (for Isotropic - same as conventional), L (for Linear increase in strength with depth below the profile line with which these material data are associated), N (for Nonlinear shear strength envelope), or R (for linear increase in shear strength with depth below designated Reference elevation).

UNRECOGNIZED CHARACTER(S) TO DESIGNATE CIRCULAR OR NONCIRCULAR SHEAR SURFACE
LEADING CHARACTER INPUT = ___
LINE INPUT = __________
The character string which was read as input to designate the type of shear surface did not start with one of the acceptable characters: C (for Circular), or N (for Noncircular).

UNRECOGNIZED CHARACTER(S) TO DESIGNATE IF SEARCH TO BE PERFORMED SHOULD BE BLANK OR START WITH THE CHARACTER 'S'
LEADING CHARACTER INPUT = ___
LINE INPUT = __________
The character string which was read as input to designate either a singular shear surface or an automatic search did not start with one of the acceptable characters: "blank" (for Singular surface), or S (for Automatic search).

UNRECOGNIZED CHARACTER(S) TO DESIGNATE IF CIRCLE IS THROUGH SPECIFIED POINT OR TANGENT TO LINE SHOULD START WITH CHARACTER 'P' OR 'T'
LEADING CHARACTER INPUT = ___
LINE INPUT = __________
The character string which was read as input to designate the radius of the single circular shear surface did not start with one of the acceptable characters: P (for Point), or T (for Tangent).

UNRECOGNIZED CHARACTER(S) TO DESIGNATE INITIAL MODE OF SEARCH SHOULD START WITH CHARACTER P, T OR R
LEADING CHARACTER INPUT = ___
LINE INPUT = __________

The character string which was read as input to designate the radius of the initial circular search surface did not start with one of the acceptable characters: P (for Point), T (for Tangent), or R (for Radius).

UNRECOGNIZED SUB-COMMAND WORD FOR ANALYSIS/COMPUTATION DATA INPUT LINE = ___
THE FIRST THREE CHARACTERS WERE RECOGNIZED AS ___
THE ERROR WAS DETECTED WHILE READING DATA WHICH ARE REQUIRED BASED ON THE PREVIOUS COMMAND WORD - THE PREVIOUS COMMAND WORD WAS DETERMINED FROM THE FOLLOWING LINE OF DATA - __________
The first three character string which was read as input to designate a subcommand word did not start with one of the acceptable characters strings listed in Table 13.3 or in Appendix D.

* V *

VALUE OF SIDE FORCE INCLINATION BECAME OUTSIDE RANGE OF FROM ___ TO ___ DEGREES
The value of the side force inclination has fallen outside the preprogrammed

limits during the iterative solution for the factor of safety using Spencer's procedure. The allowable limits are printed with this error message. Some of the possible causes for this error message being printed are: (1) There are excessive amounts of tension near the crest of the slope - a crack probably needs to be introduced; (2) Excessively high compressive stresses or various degrees of tensile stresses may exist near the toe of the slope - this unreasonable condition is likely to be indicative of a shear surface which is excessively steep near the toe of the slope; (3) The estimated value for the trial factor of safety may be excessively low - the assumed initial trial value may need to be increased; or (4) The shear strength along the upper portion of the shear surface may be very high relative to the shear strength along other portions of the shear surface such that the slope is "hanging" by the upper zones of soil - factors of safety calculated by limit equilibrium procedures may not be meaningful and more careful attention may need to be given to the strength which can actually be "mobilized" in the much stronger soil zone.

* W *

///// WARNING ///// EFFECTIVE OR TOTAL NORMAL STRESS ON SHEAR SURFACE IS NEGATIVE AT POINTS ALONG THE LOWER ONE HALF OF THE SHEAR SURFACE - SOLUTION MAY NOT BE A VALID SOLUTION
This message is printed at the end of the final output tables when the computed total or effective stress is negative along the lower one half of the shear surface. The lower one half of the shear surface is defined as the portion of the shear surface where the x coordinate lies between the toe-most value and the average of the left-most and right-most values. This message and the associated problem will typically occur when the shear surface is excessively steep near the toe of the slope. Ordinarily, any solution where this message is printed should be considered unreasonable.

///// WARNING ///// FORCES BETWEEN SLICES ARE NEGATIVE AT POINTS ALONG THE LOWER ONE HALF OF THE SHEAR SURFACE - SOLUTION MAY NOT BE A VALID SOLUTION
This message is printed at the end of the final output tables when the computed forces between slices are negative along the lower one half of the shear surface. The lower one half of the shear surface is defined as the portion of the shear surface where the x coordinate lies between the toe-most value and the average of the left-most and right-most values. This message and the associated problem will typically occur when the shear surface is excessively steep near the toe of the slope. Ordinarily, any solution where this message is printed should be considered unreasonable.

***** WARNING ***** ONE OF CHECK SUMS IS TOO LARGE
Once the factor of safety is computed the program performs several checks on the final computed values. The checks consist of (1) a summation of forces in the vertical direction (all procedures), (2) a summation of forces in the horizontal direction (Spencer's and the force equilibrium procedures only), (3) a summation of moments (Spencer's and the simplified Bishop procedures only), and (4) a shear strength check which consists of summing the differences between the shear force computed from the static equilibrium equations and the shear force computed from the Mohr-Coulomb equations for each slice. The summations of forces must not exceed the allowable force imbalance specified for

the convergence tolerance and the summation of moments must not exceed the specified moment imbalance for convergence. If any of the summations do not satisfy these criteria, this message is printed.

///// WARNING ///// SHEAR STRESS AT SOME POINTS ALONG THE SHEAR SURFACE IS NEGATIVE - SOLUTION MAY NOT BE A VALID SOLUTION.
This message is printed at the end of the final output tables when the computed shear stress is negative, i.e., when the computed shear stress acts in the opposite direction from the direction expected based on the direction of sliding. This error will occur when the normal stress on the base on the slice becomes excessively negative. A solution should ordinarily be rejected when this error occurs. The error may occur when (1) there is excessive tension near the crest of the slope - a tension crack may be needed, or (2) the shear surface is excessively steep near the toe of the slope - the shear surface may need to be flattened near the toe of the slope.

APPENDIX C: ARRAY SIZE LIMITS

1. A number of the input variables for UTEXAS3 are stored in fixed-size, dimensioned arrays. Accordingly, the number of these quantities is limited by the dimensioned size of the arrays. If any data exceed the dimensioned array sizes, an appropriate error message is issued and computations are interrupted with an appropriate action depending on the severity of the error. The quantities and maximum numbers allowed are shown in Table C1.

Table C1
Array Size Limits in UTEXAS3

Variable	Maximum Number Allowed
Maximum number of profile lines (MAXPRL)	20
Maximum number of points on an individual profile line (MAXPLP)	30
Maximum number of materials (MAXMAT)	20
Maximum number of failure plane orientations used to define anisotropic shear strength values for a given material AND maximum number of points used to define a nonlinear (curved) shear strength envelope (MAXMPT)	19
Maximum number of piezometric lines (MAXPZL)	4
Maximum number of points on a given, individual piezometric line (MAXPZP)	30
Maximum number of "gridded" points for interpolation of pore water pressures - all points (MAXINP)	300
Maximum number of points used to define the slope geometry (MAXSLP)	50
Maximum number of points used to define surface pressures (MAXSUP)	50
Maximum number of concentrated forces (MAXCNF)	10
Maximum number of soil reinforcement lines (MAXRFL)	40
Maximum number of points on an individual soil reinforcement line (MAXRLP)	5
Maximum number of coordinates on the shear surface, including points which are generated by the computer program = maximum number of slices plus one (MAXSSP)	100
Maximum number of coordinate points specified by input data to define a noncircular shear surface for an automatic search (MAXNCP)	30

APPENDIX D: UTEXAS3 DATA INPUT SHORT FORM

1. Data files for UTEXAS3 are command word based. Thus, data files consist of command words and data that are associated with some of the command words. This appendix is intended to assist in preparing batch data entry files by providing quick reference tables for all command words and any associated data. This should help ensure that the required data for each command word is entered properly in the data file. Each command word for which data are required is listed in Table D1. Those command words that require no data are listed in Table D2. The data information listed in Table D1 is in the order required by the program. Tables D3, D4, D5, and D6 provide lists of items that can be used in the appropiate locations.

2. Data files will contain various command words. The minimum data file command word requirements include PROfile lines, MATerial property, ANAlysis/computation data, and COMpute. Examples of complete data files can be found in Appendix E.

Table D1

Data Entry Short Form - Command Words That Require Additional Data

---

HEAding
  line 1 of heading
  line 2 of heading
  line 3 of heading

PROfile lines
  1 (line number) 1 (material type) optional label
  x coordinate y coordinate
  blank line ends profile line
  blank line ends profile data group

MATerial property
  1 (material type) optional material label
  unit weight
  type of shear strength data - 1 or 2 characters - SEE TABLE D3
    shear strength data
  type of piezometric data - 2 characters - SEE TABLE D4
    piezometric data
  blank line ends material property data group

PIEzometric line data
  piezometric line number unit weight (optional) optional label
  x coordinate y coordinate
  blank line ends piezometric line
  blank line ends piezometric line data group

INTerpolation data for pore water pressures
    type of data - pore pressure or r-sub-u data
    x coordinate y coordinate pressure/r-sub-u value material (0 for all)
    blank line ends current data
    blank line ends interpolation data group

SLOpe geometry data
    x coordinate y coordinate
    blank line ends slope geometry data group

SURface pressure data
    x coordinate y coordinate normal stress shear stress
    blank line ends surface pressure data group

FORces
    1 (number to identify concentrated force) x coordinate y coordinate
        horizontal component of force /OR/ magnitude of force
        vertical component of force /OR/ inclination of force
        designation of how forces are specified (1 = horizontal and vertical
            components; 2 = magnitude and inclination)
    blank line ends concentrated forces data group

REInforcement data
    1 (reinforcement line number) maximum reinforcement rotation angle
        designation of how forces are to be applied to slices (1 = forces
                applied to boundaries between slices and base of slices; 2 =
                forces applied to base of slices)
    x coordinate y coordinate longitudinal (axial) force transverse (shear)
        force
    blank line ends current reinforcement line data
    blank line ends reinforcement line data group

ANAlysis and computation data
    type of surface search/no search - 2 characters - SEE TABLE D5
        surface and search data
    blank line unless optional input quantities - SEE TABLE D6

Table D2

Data Entry Short Form - Common Command Words That Require No Additional Data

****
COMpute
NO compute
PLOt
OFF plot output
FIRst stage computation data
SECond stage computation data

Table D3

Type of Shear Strength Data

The first five conventional strengths only requies a single character or character string, two-stage strengths are designated by a pair of characters or character strings.

Conventional shear strength
  input:
    cohesion parameter internal friction angle

Linear increase with depth
  input:
    cohesion parameter along profile line rate of increase

Reference - shear strength increases with depth below a reference plane
  input:
    reference elevation c parameter rate of increase

Anisotropic shear strength
  input:
    failure plane orientation c parameter phi angle
    blank line ends strength values

Nonlinear Mohr-Coulomb envelope
  input:
    normal stress shear stress
    blank line ends strength values

2-stage Linear strength envelopes
  input on a single line:
    c parameter from τ_{ff} vs. $\bar{\sigma}_{fc}$ from isotropically consolidated-undrained triaxial compression test
    ϕ parameter from τ_{ff} vs. $\bar{\sigma}_{fc}$ from isotropically consolidated-undrained triaxial compression test
    c parameter for effective stress envelope (either from S or $\bar{R}$ test)
    ϕ parameter for effective stress envelope (either from S or $\bar{R}$ test)

2-stage Nonlinear strength envelopes
  input on a single line for each effective normal stress:
    effective normal stress on failure plane at consolidation
    shear stress from isotropically consolidated-undrained compression test
    shear stress from effective stress envelope
    blank line ends strength values

Table D4

Type of Piezometric Data

NO pore pressure
  input:
    none

Constant Pore pressure
  input:
    value of pore pressure

Constant R_u value
  input:
    value of r_u

Piezometric Line
  input:
    identification number of the piezometric line -
      MUST enter PIEzometric data

Interpolate Pore water pressure
  input:
    no data following this choice -
      MUST enter INTerpolation data

Interpolate R_u values
  input:
    no data following this choice -
      MUST enter INTerpolation data

Table D5

Type of Shear Surface and Analysis

Circular "_"(=blank) single surface
input:
x coord for center y coord for center radius of circle
1 char to define radius if not entered on previous line:
Point - circle passes through a fixed point-
MUST input on next line the x and y coordinates of the fixed point
Tangent - circle is tangent to a horizontal line
MUST input on next line the y coordinate of the line
blank line to end all ANALYSIS/COMPUTATION data or proceed to optional input quantities subcommand words

Circular Search
input:
one line { 1) starting x coord for center 2) starting y coord for center
3) accuracy or minimum grid spacing (recommend 1% of slope height)
4) y coord for limiting depth for circles
1 character indicating type of initial search
Point - circles pass through a fixed point -
MUST input next line of: x coord y coord for fixed point
Tangent - circles all tangent to a horizontal line -
MUST input next line of: y coord of horizontal line
Radius - circles all have the same radius -
MUST input next line of: radius value
blank line to end all ANALYSIS/COMPUTATION data or proceed to optional input quantities subcommand words

Noncircular "_"(=blank) single surface
input:
x coord y coord to define the noncircular shear surface
blank line to end shear surface data
blank line to end all ANALYSIS/COMPUTATION data or proceed to optional input quantities subcommand words

Noncircular Search
input:
x coord y coord to define shear surface information about how point can be shifted
- if blank, point is moveable and is moved perpendicular to the shear surface
- if numerical value, point is moveable and the input value defines the direction of movement. The value should be an angle measurement in degrees from the horizontal with counterclockwise being positive
- if FIX, point is not moved during search

(Continued)

Table D5 (Concluded)

	blank line to end shear surface data
both on one line	1) initial shift distance note: final shift distance or accuracy will be 10% of this distance
	2) maximum steepness permitted for shear surface near toe portion - optional default value of 50° is used if none input
	blank line to end all analysis/computation data or proceed to optional input quantities subcommand words

Table D6

Type of Optional Input Quantities

TWO-stage computations
input: none
Designates that two-stage stability computations are to be performed

THRee-stage computations
input: none
Designates that three-stage stability computations are to be performed

FACtor of safety
input: initial trial value for factor of safety
(default is 3.0)

SIDe force inclination
input: initial trial value for side-force inclination, in deg
(default is 15 deg)

ITEration limit
input: maximum number of iterations
(default is 40)

FORce imbalance
input: maximum force imbalance permitted for convergence
(default is 100)

MOMent imbalance
input: maximum moment imbalance permitted for convergence
(default is 100)

CHAnge initial trial factor of safety
input: none (default is off)
The initial trial value is the default/input value for each search type.

OPPosite sign convention
input: none (default is off)
Toggles sign convention from assumed one in the program to the opposite convention.

SHOrt-form output
input: none (default is off)
Toggles short-form versus long-form output.

SUBtended angle
input: subtended angle for slice generation (default is 3 deg) requires circular shear surface

(Continued)

Table D6 (Concluded)

ARC length
    input: maximum arc length for slice generation (default is length generated by 3 deg subtended angle) requires circular shear surface

CRAck length
    input: vertical (tension) crack depth (default is no crack)

BASe length
    input: maximum slice base length for slice generation (default is length generated by 30 slices) requires noncircular shear surface

INCrements for slice generation
    input: number of increments to subdivide the shear surface (default is 30) requires a noncircular shear surface

STOp
    input: none Stops an automatic search with a circular shear surface after the initial mode is completed. (default is off)

CRItical
    input: none This continues the automatic search after a STOP has been issued. (default is on)

WATer depth
    input: depth of water or other fluid in vertical crack (default is zero, no water)

UNIt weight of water
    input: unit weight of water or other fluid in vertical crack (default is 62.4)

SEIsmic coefficient
    input: seismic coefficient (default is 0)

PROcedure for computation of F
    input: single character indicating one of the following procedures:
- Spencer's procedure (default value)
- Bishop procedure
- Corps of Engineers' Modified Swedish side force assumption with force equilibrium procedure REQUIRES next line:
    - side force inclination - measured in degrees from the horizontal
- Lowe for Lowe and Karafiath's side force assumption with force equilibrium procedure

input a blank line to end all optional input quantities

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268 p. : ill. ; 28 cm. -- (Instruction report ; GL-87-1 vol. 4)
Includes bibliographical references.
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	Title	Date
Miscellaneous Paper GL-79-19	Results of Geotechnical Computer Usage Survey	Aug 1979
Miscellaneous Paper GL-82-1	Geotechnical Computer Program Survey	Mar 1982
Instruction Report GL-83-1	Geotechnical Construction Control Data Base System	Apr 1983
Instruction Report GL-84-1	Boring Information and Subsurface Data Base Package, User's Guide	Sep 1984
Miscellaneous Paper GL-85-8	Criteria for Limit Equilibrium Slope Stability Program Package	May 1985
Instruction Report GL-85-1	Microcomputer Boring and Subsurface Data Package, User's Guide	Sep 1985
Instruction Report GL-85-2	Piezometer Data Base Package, User's Guide	Oct 1985
Instruction Report GL-87-1	User's Guide: UTEXAS2 Slope-Stability Package; Volume I, User's Manual	Aug 1987
Miscellaneous Paper GL-87-5	An Examination of Slope Stability Computation Procedures for Sudden Drawdown	Sep 1987
Instruction Report GL-87-1	User's Guide: UTEXAS2 Slope-Stability Package; Volume II, Theory	Feb 1989
Miscellaneous Paper SL-91-2	Evaluation of "SeeSTAT" Software Program for Archiving, Computing, and Reporting of Concrete Test Results	May 1991
Miscellaneous Paper ITL-91-2	Geotechnical Application Programs for CADD (Computer-Aided Design and Drafting) Systems	Apr 1991
Instruction Report GL-91-2	Microcomputer Geotechnical Quality Assurance of Compacted Earth Fill Data Package: User's Guide	Aug 1991
Instruction Report GL-92-2	User's Guide for the Boring Log Design File Builder, Version 2.01	May 1992
Miscellaneous Paper GL-92-31	McCON–A General Contouring Program for Personal Computers	Sep 1992
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	Title	Date
Technical Report K-78-1	List of Computer Programs for Computer-Aided Structural Engineering	Feb 1978
Instruction Report O-79-2	User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Mar 1979
Technical Report K-80-1	Survey of Bridge-Oriented Design Software	Jan 1980
Technical Report K-80-2	Evaluation of Computer Programs for the Design/Analysis of Highway and Railway Bridges	Jan 1980
Instruction Report K-80-1	User's Guide: Computer Program for Design/Review of Curvilinear Conduits/Culverts (CURCON)	Feb 1980
Instruction Report K-80-3	A Three-Dimensional Finite Element Data Edit Program	Mar 1980
Instruction Report K-80-4	A Three-Dimensional Stability Analysis/Design Program (3DSAD)	
	Report 1: General Geometry Module	Jun 1980
	Report 3: General Analysis Module (CGAM)	Jun 1982
	Report 4: Special-Purpose Modules for Dams (CDAMS)	Aug 1983
Instruction Report K-80-6	Basic User's Guide: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Instruction Report K-80-7	User's Reference Manual: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Technical Report K-80-4	Documentation of Finite Element Analyses	
	Report 1: Longview Outlet Works Conduit	Dec 1980
	Report 2: Anchored Wall Monolith, Bay Springs Lock	Dec 1980
Technical Report K-80-5	Basic Pile Group Behavior	Dec 1980
Instruction Report K-81-2	User's Guide: Computer Program for Design and Analysis of Sheet Pile Walls by Classical Methods (CSHTWAL)	
	Report 1: Computational Processes	Feb 1981
	Report 2: Interactive Graphics Options	Mar 1981
Instruction Report K-81-3	Validation Report: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Feb 1981
Instruction Report K-81-4	User's Guide: Computer Program for Design and Analysis of Cast-in-Place Tunnel Linings (NEWTUN)	Mar 1981
Instruction Report K-81-6	User's Guide: Computer Program for Optimum Nonlinear Dynamic Design of Reinforced Concrete Slabs Under Blast Loading (CBARCS)	Mar 1981
Instruction Report K-81-7	User's Guide: Computer Program for Design or Investigation of Orthogonal Culverts (CORTCUL)	Mar 1981
Instruction Report K-81-9	User's Guide: Computer Program for Three-Dimensional Analysis of Building Systems (CTABS80)	Aug 1981
Technical Report K-81-2	Theoretical Basis for CTABS80: A Computer Program for Three-Dimensional Analysis of Building Systems	Sep 1981
Instruction Report K-82-6	User's Guide: Computer Program for Analysis of Beam-Column Structures with Nonlinear Supports (CBEAMC)	Jun 1982

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	Title	Date
Instruction Report K-82-7	User's Guide: Computer Program for Bearing Capacity Analysis of Shallow Foundations (CBEAR)	Jun 1982
Instruction Report K-83-1	User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Jan 1983
Instruction Report K-83-2	User's Guide: Computer Program for Generation of Engineering Geometry (SKETCH)	Jun 1983
Instruction Report K-83-5	User's Guide: Computer Program to Calculate Shear, Moment, and Thrust (CSMT) from Stress Results of a Two-Dimensional Finite Element Analysis	Jul 1983
Technical Report K-83-1	Basic Pile Group Behavior	Sep 1983
Technical Report K-83-3	Reference Manual: Computer Graphics Program for Generation of Engineering Geometry (SKETCH)	Sep 1983
Technical Report K-83-4	Case Study of Six Major General-Purpose Finite Element Programs	Oct 1983
Instruction Report K-84-2	User's Guide: Computer Program for Optimum Dynamic Design of Nonlinear Metal Plates Under Blast Loading (CSDOOR)	Jan 1984
Instruction Report K-84-7	User's Guide: Computer Program for Determining Induced Stresses and Consolidation Settlements (CSETT)	Aug 1984
Instruction Report K-84-8	Seepage Analysis of Confined Flow Problems by the Method of Fragments (CFRAG)	Sep 1984
Instruction Report K-84-11	User's Guide for Computer Program CGFAG, Concrete General Flexure Analysis with Graphics	Sep 1984
Technical Report K-84-3	Computer-Aided Drafting and Design for Corps Structural Engineers	Oct 1984
Technical Report ATC-86-5	Decision Logic Table Formulation of ACI 318-77, Building Code Requirements for Reinforced Concrete for Automated Constraint Processing, Volumes I and II	Jun 1986
Technical Report ITL-87-2	A Case Committee Study of Finite Element Analysis of Concrete Flat Slabs	Jan 1987
Instruction Report ITL-87-1	User's Guide: Computer Program for Two-Dimensional Analysis of U-Frame Structures (CUFRAM)	Apr 1987
Instruction Report ITL-87-2	User's Guide: For Concrete Strength Investigation and Design (CASTR) in Accordance with ACI 318-83	May 1987
Technical Report ITL-87-6	Finite-Element Method Package for Solving Steady-State Seepage Problems	May 1987
Instruction Report ITL-87-3	User's Guide: A Three Dimensional Stability Analysis/Design Program (3DSAD) Module	Jun 1987
	Report 1: Revision 1: General Geometry	Jun 1987
	Report 2: General Loads Module	Sep 1989
	Report 6: Free-Body Module	Sep 1989

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	Title	Date
Instruction Report ITL-87-4	User's Guide: 2-D Frame Analysis Link Program (LINK2D)	Jun 1987
Technical Report ITL-87-4	Finite Element Studies of a Horizontally Framed Miter Gate Report 1: Initial and Refined Finite Element Models (Phases A, B, and C), Volumes I and II Report 2: Simplified Frame Model (Phase D) Report 3: Alternate Configuration Miter Gate Finite Element Studies–Open Section Report 4: Alternate Configuration Miter Gate Finite Element Studies–Closed Sections Report 5: Alternate Configuration Miter Gate Finite Element Studies–Additional Closed Sections Report 6: Elastic Buckling of Girders in Horizontally Framed Miter Gates Report 7: Application and Summary	Aug 1987
Instruction Report GL-87-1	User's Guide: UTEXAS2 Slope-Stability Package; Volume I, User's Manual	Aug 1987
Instruction Report ITL-87-5	Sliding Stability of Concrete Structures (CSLIDE)	Oct 1987
Instruction Report ITL-87-6	Criteria Specifications for and Validation of a Computer Program for the Design or Investigation of Horizontally Framed Miter Gates (CMITER)	Dec 1987
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Instruction Report ITL-88-1	User's Guide: Computer Program for Analysis of Planar Grid Structures (CGRID)	Feb 1988
Technical Report ITL-88-1	Development of Design Formulas for Ribbed Mat Foundations on Expansive Soils	Apr 1988
Technical Report ITL-88-2	User's Guide: Pile Group Graphics Display (CPGG) Post-processor to CPGA Program	Apr 1988
Instruction Report ITL-88-2	User's Guide for Design and Investigation of Horizontally Framed Miter Gates (CMITER)	Jun 1988
Instruction Report ITL-88-4	User's Guide for Revised Computer Program to Calculate Shear, Moment, and Thrust (CSMT)	Sep 1988
Instruction Report GL-87-1	User's Guide: UTEXAS2 Slope-Stability Package; Volume II, Theory	Feb 1989
Technical Report ITL-89-3	User's Guide: Pile Group Analysis (CPGA) Computer Group	Jul 1989
Technical Report ITL-89-4	CBASIN–Structural Design of Saint Anthony Falls Stilling Basins According to Corps of Engineers Criteria for Hydraulic Structures; Computer Program X0098	Aug 1989

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	Title	Date
Technical Report ITL-89-5	CCHAN–Structural Design of Rectangular Channels According to Corps of Engineers Criteria for Hydraulic Structures; Computer Program X0097	Aug 1989
Technical Report ITL-89-6	The Response-Spectrum Dynamic Analysis of Gravity Dams Using the Finite Element Method; Phase II	Aug 1989
Contract Report ITL-89-1	State of the Art on Expert Systems Applications in Design, Construction, and Maintenance of Structures	Sep 1989
Instruction Report ITL-90-1	User's Guide: Computer Program for Design and Analysis of Sheet Pile Walls by Classical Methods (CWALSHT)	Feb 1990
Technical Report ITL-90-3	Investigation and Design of U-Frame Structures Using Program CUFRBC Volume A: Program Criteria and Documentation Volume B: User's Guide for Basins Volume C: User's Guide for Channels	May 1990
Instruction Report ITL-90-6	User's Guide: Computer Program for Two-Dimensional Analysis of U-Frame or W-Frame Structures (CWFRAM)	Sep 1990
Instruction Report ITL-90-2	User's Guide: Pile Group–Concrete Pile Analysis Program (CPGC) Preprocessor to CPGA Program	Jun 1990
Technical Report ITL-91-3	Application of Finite Element, Grid Generation, and Scientific Visualization Techniques to 2-D and 3-D Seepage and Groundwater Modeling	Sep 1990
Instruction Report ITL-91-1	User's Guide: Computer Program for Design and Analysis of Sheet-Pile Walls by Classical Methods (CWALSHT) Including Rowe's Moment Reduction	Oct 1991
Instruction Report ITL-87-2 (Revised)	User's Guide for Concrete Strength Investigation and Design (CASTR) in Accordance with ACI 318-89	Mar 1992
Technical Report ITL-92-2	Fiinite Element Modeling of Welded Thick Plates for Bonneville Navigation Lock	May 1992
Technical Report ITL-92-4	Introduction to the Computation of Response Spectrum for Earthquake Loading	Jun 1992
Instruction Report ITL-92-3	Concept Design Example, Computer Aided Structural Modeling (CASM) Report 1: Scheme A Report 2: Scheme B Report 3: Scheme C	 Jun 1992 Jun 1992 Jun 1992
Instruction Report ITL-92-4	User's Guide: Computer-Aided Structural Modeling (CASM) - Version 3.00	Apr 1992
Instruction Report ITL-92-5	Tutorial Guide: Computer-Aided Structural Modeling (CASM) - Version 3.00	Apr 1992

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	Title	Date
Contract Report ITL-92-1	Optimization of Steel Pile Foundations Using Optimality Criteria	Jun 1992
Technical Report ITL-92-7	Refined Stress Analysis of Melvin Price Locks and Dam	Sep 1992
Contract Report ITL-92-2	Knowledge-Based Expert System for Selection and Design of Retaining Structures	Sep 1992
Contract Report ITL-92-3	Evaluation of Thermal and Incremental Construction Effects for Monoliths AL-3 and AL-5 of the Melvin Price Locks and Dam	Sep 1992
Instruction Report GL-87-1	User's Guide: UTEXAS3 Slope-Stability Package; Volume IV, User's Manual	Nov 1992